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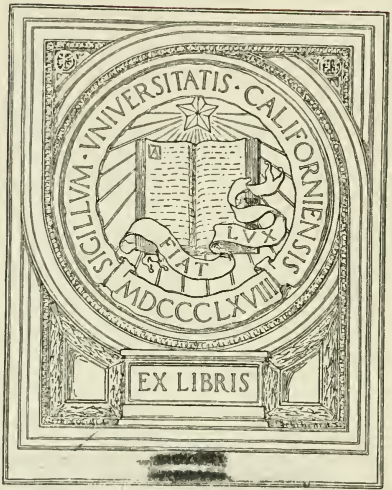

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REPRINTS OF ARTICLES ON PERIMETRY BY DRS. C. E. FERREE AND GERTRUDE RAND AND OTHERS.

1. Some Areas of Color Blindness of an Unusual Type in the Peripheral Retina, Ferree and Rand, Journal of Experimental Psychology, Vol. 11, No. 4, August 1917.
2. An Illuminated Perimeter with Campimeter Features, Ferree and Rand, American Journal of Ophthalmology, Vol. 5, No. 6, June, 1922.
3. Perimetry: Variable Factors Influencing the Breadth of the Color Fields, Ferree and Rand, American Journal of Ophthalmology, Vol. 5, No. 11, November, 1922.
4. The Effect of Intensity of Stimulus on the Size and Shape of the Color Fields and Their Order of Ranking as to Breadth, Ferree and Rand, American Journal of Ophthalmology, Vol. 6, No. 6, June, 1923.
5. Effect of Brightness of Preexposure and Surrounding Field on Breadth and Shape of the Color Fields for Stimuli of Different Sizes, Ferree and Rand, American Journal of Ophthalmology, Vol. 7, No. 11, November, 1924.
6. The Blind Spot for Achromatic and Chromatic Stimuli, Ferree and Rand, American Journal of Ophthalmology, Vol. 8, No. 8, August, 1925.
7. Studies in Perimetry. 1. Preliminary Work on a Diagnostic Scale for the Form Field, Ferree, Rand and Monroe, American Journal of Ophthalmology, Vol. 9, No. 2, February, 1926.
8. Effect of Size of Stimulus on Size and Shape of Color Fields, Ferree and Rand, American Journal of Ophthalmology, Vol. 10, No. 6, June, 1927.
9. Studies in Perimetry. 2. Preliminary Work on a Diagnostic Scale for the Color Fields, Ferree, Rand, and Monroe, American Journal of Ophthalmology, Vol. 12, No. 4, April, 1929.
10. Studies in Perimetry. 3. ErrORS of Refraction, Age, and Sex Relation to Size of the Form Field, Ferree, Rand and Monroe, American Journal of Ophthalmology, Vol. 12, No. 8, August, 1929.

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SOME AREAS OF COLOR BLINDNESS OF AN UNUSUAL TYPE IN THE PERIPHERAL RETINA

BY C. E. FERREE AND GERTRUDE RAND
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At the psychophysical section of the first Congress for Experimental Psychology held at Giessen April 18–21, 1904, F. Schumann reported what he termed an unusual case of color blindness (his own).[1] So far as the ability to get the positive sensation is concerned, Dr. Schumann is, according to the report, totally blind to green and partially so to red.[2] In addition his case presents the following features. (1) While green light does not arouse a sensation of green, it does give red after-image and contrast sensations. Red light on the other hand gives a positive sensation but does not give either after-image or contrast sensations.[3] (2) A colorless mixed light can be matched by combining homogeneous red and green lights, but quite a little greater proportion of green is needed to give the neutral sensation than is required for the immediately surrounding retina. In the investigation of the complementary or cancelling reaction, a combination of the complementary colors to gray was made for the surrounding portions of the retina and this stimulus was presented to the color-blind area. In each case it was seen as gray, not as the color complementary to that for which the spot was blind. We need scarcely point out that in making this test it was necessary to determine whether the amount of colored light employed would have aroused color sensation had it not been combined with its complementary color. This was done in two ways: (*a*) The amount of color used to form the combination to gray was presented to the color-blind area, combined with the proper value of a substitute sector of the gray of the brightness of the color to which the area was blind; and (*b*) the threshold was determined in the color-blind area for the color complementary to that to which the area was blind, and its value compared with the amount used in making the combination to gray. The results of both determinations showed that a true complementary action was present.

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[1] Schumann, F., 'Ein ungewöhnlicher Fall von Farbenblindheit,' Bericht über den I. Kongress für experimentelle Psychologie in Giessen, 1904, pp. 10–13. See also G. E. Muller's discussion of the report, *ibid.*, pp. 20–21.

[2] His diagnosis that he is partially sensitive to red was based on two facts. (*a*) Red in the region of 670 $\mu\mu$ gave a sensation which was plainly different from yellow and could not be matched by a full spectrum gray. And (2) orange which to the normal eye appeared distinctly reddish, appeared to him a pure yellow. From this point in the orange towards the short wave-length end of the spectrum three qualities were sensed: a yellow, a blue and a band between them which could be matched with a full spectrum gray. On these facts was based the diagnosis of blindness to green.

[3] While a red light does not give green contrast sensation, it does produce an effect on a neighboring field which raises the threshold or diminishes the sensitivity to red. That is, a gray ring on a red ground appears gray but an amount of red can be added to it without being sensed which is supraliminal when red is not present in the surrounding field. In other words a physiological induction seems to be present which inhibits the complementary excitation although the induced excitation does not itself arouse sensation. We have here, therefore, another evidence that the complementary and induction relations between red and green are intact, the ability of the green excitation to arouse sensation alone being absent.

The peripheral retina spots while similar in a general way to the case described by Schumann present the following points of difference. (1) There was no detectable weakening of the sensitivity to the complementary or antagonistic color in the areas in question. And (2) no more of the color to which the area was blind was required to combine to gray with the antagonistic or complementary color than was needed on the normal areas of the retina immediately adjacent.

In the presentation of results space will be taken for only two observers, selected because of rather wide differences in the number, size and location of the spots. In Chart I. is shown results for Observer R. and in Chart II. for Observer C. The Hering pigment papers were used as stimuli and the investigation was made with surrounding field and preëxposure of the brightness of the color in each case. The limits of sensitivity were determined for each color in 16 meridians and these points are connected to give outline maps of color sensitivity for stimuli of the intensity used. In working in any of the above-mentioned meridians the stimulation was given at points separated by no more than 1°. When a gap or a significant depression in sensitivity was found, the campimeter was rotated and the investigation made in a sufficient number of near-lying meridians to give a careful outline of the deficient area. These areas are represented on the charts in black, with letters to indicate the colors to which there is a deficiency. In case there is total blindness to the stimulus used, the spot is repre-

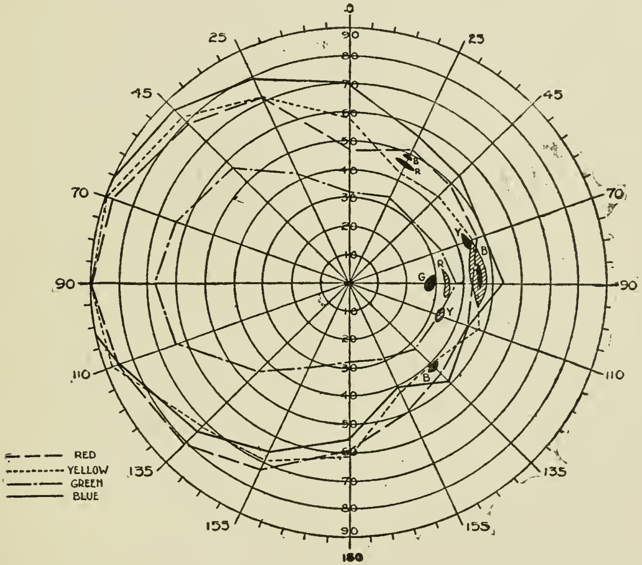

CHART I

Showing for Observer R the Areas of the Peripheral Retina having the Schumann Type of Color Blindness. These areas are represented in black, with letters to indicate the colors to which there is a deficiency. In case there is total blindness to the stimulus used, the area is represented in solid black; in case there is only a marked depression of sensitivity, the area is shaded. In this latter case areas are represented only when the depression amounts nearly to blindness. The only effect of using spectrum lights of very high intensity: red (670 $\mu\mu$), 36.76 × 10^{-8} watt at pupil of eye; yellow (581 $\mu\mu$), 31.93 × 10^{-8} watt at pupil of eye; green (522 $\mu\mu$), 4.24 × 10^{-8} watt at pupil of eye; and blue (471 $\mu\mu$), 2.90 × 10^{-8} watt at pupil of eye, was to narrow in some cases the area of the spots previously mapped by means of the pigment paper stimuli.

sented in solid black; in case there is only a marked depression of sensitivity the area is shaded. In this latter case areas are represented only when the depression of sensitivity amounts nearly to blindness. They were, for example, so insensitive that the color response could not be aroused when an unfavorable brightness of surrounding field or preëxposure was used.

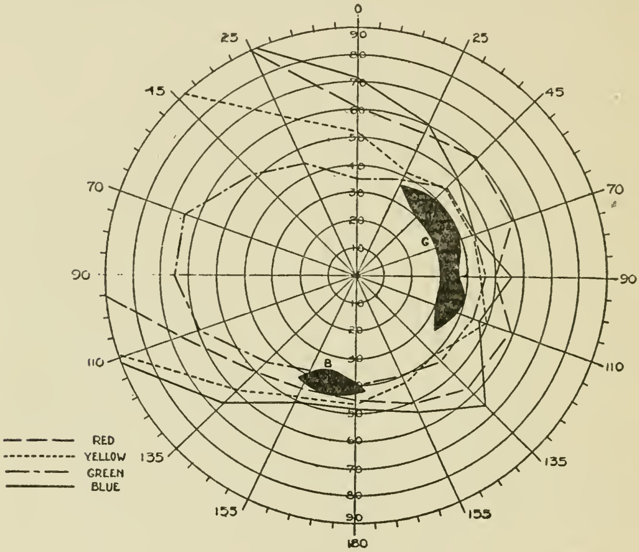

Chart II

Showing for Observer C the Areas of the Peripheral Retina having the Schumann Type of Color Blindness. The conditions of investigation and method of representation is the same in this chart as in Chart I. The results for Observers R and C are selected for presentation here because of the somewhat unusually wide difference that was found in the number, size and location of their spots.

In discussing his own case, Schumann seems to think that the phenomenon indicates that there must be more than one functional level involved in the production of visual sensation: peripheral or sub-cortical, and cortical. One of these, the peripheral or the sub-cortical, is the locus of the complementary or cancelling action, and the after-image and contrast reactions. Green light in his case arouses these three reactions because the level concerned in producing them is functionally normal. Green does not arouse the positive sensation, however, because there is functional deficiency in the remaining level or levels. G. E. Müller, who also made supplementary tests and experiments on Schumann and discussed Schumann's report at the Congress in Giessen, concurs strongly in the conception that more than one functional level is needed to explain the Schumann case. At this same Congress Müller[1] discusses seven types of color-blindness which he further believes can be explained best on the conception of more than one specific functional level, the processes of which may be separately deficient. His theory of color vision is in fact here elaborated to include both peripheral and central visual processes. While we have no wish to engage in theoretical discussions at this stage in our own work, it may not be out of place, in addition to the results presented in this paper, to call to mind in this general connection our experiments of the effect of the achromatic excitation on the chromatic which seemed to indicate very strongly that this effect both quantitative and qualitative takes place at some level posterior to that of the cancelling, after-image, and contrast reactions.[2] We have also obtained other results, as yet unpublished, on contrast induction in the far periphery of the retina which seem to indicate that the deficiency which for these portions of the retina prevents the color stimulation from producing sensation is in part at least posterior to the level at which induction takes place. Moreover, unless the complementary action were intact in case of blindness to one color over a whole or part of the retina, it would seem that white light should always be sensed by the subject in the tone complementary to that for which the blindness exists.[1] Or to put the matter more conservatively in terms of color-blindness testing, it would seem impossible ever in such cases to match a full spectrum gray to the color to which the subject is blind, or to all combinations of complementary colors, or to any in fact except the pair to one member of which the defect exists.

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[1] Müller, G. E., 'Die Theorie der Gegenfarben und die Farbenblindheit,' Bericht über den 1. Kongress für experimentelle Psychologie in Giessen, 1904, pp. 6–10. The conception of a central deficiency was used as early as 1868 by Niemetschek to explain color blindness (*Prager Vierteljahrschrift*, *100*, p. 224).

[2] The results of these experiments have as yet been published only in part. (See "An Experimental Study of the Fusion of Colored and Colorless Light Sensations. The Locus of the Action," *Journ. of Philos., Psychol. and Scientific Methods*, 1911, *8*, pp. 294–297.)

The fuller publication has been delayed for one reason because we have felt the need of giving a somewhat exhaustive résumé of the work that has yet been done on the subject. This work has been so scattered and unsystematic and so much of it appears hidden under titles that give no indication that it is there, that the work of compiling has been somewhat time consuming.

In the study of the eye as a recording instrument it is always a helpful feature to take our start from the physical recording instruments which respond to light. Not only are the characteristics of a given one of these instruments more accessible to study than the eye, but the instrument itself can be changed and the effect produced be noted. Also different types of instrument are accessible to study. Just as the simpler work on the study of the physical instruments serves as a helpful methodological guide in the experimental determination of the characteristics of response of the eye, so may we get methodological helps from the study of these instruments which may be of service in forming our conceptions of the actions and functional relations of the cerebro-retinal structure.

One of the characteristics of the instruments which respond to radiant energy is with the exception of the photographic plate a surface or layer in which the energy of the light-wave is transformed into an effect which it is the function of another part of the apparatus to record. This transformation, moreover, in case of some of these instruments: the selenium cell, the photoelectric cell and the photographic plate, is selective;

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[1] It is possible that an alternative explanation of the above point may be found in some of the other types of modification of existing theories, *e. g.*, Fick's and Leber's modification of the Helmholtz theory to explain the variations in the color sensitivity of the peripheral retina (see Fick, A., 'Arbeiten aus dem physiol. Laborat. der Würzburger Hochschule,' pp. 213–217; Leber, T., *Klin. Monatsblätter f. Augenheilk.*, 1873, *II*, pp. 467–473). The conception of different functional levels, however, should at least be recognized as one of the possibilities of explanation for monochromatic deficiencies, and as a very plausible and perhaps necessary assumption to explain phenomena of the kind described by Schumann and by the present writers in this paper.

i. e., it is different in amount for the different wave-lengths[1] and the selectiveness varies with the intensity of light used. There is an analogue to this in the selectiveness of the achromatic response of the eye to wave-length and the variation of this selectiveness with change of intensity of light. (In case of the achromatic response this is known as the Purkinje phenomenon.) Some of these instruments also show like the eye a lag in coming to their maximum of response, a fatigue effect, and an after-effect. All of these effects are characteristic of the receiving part of the instrument, not of the recording mechanism. The final form into which the response of the instrument is put is, however, a function of the recording part of the apparatus. Moreover, either one of these parts of the apparatus may, we scarcely need point out, be separately deficient without the impairment of the other. In view of the general similarity in characteristics of response shown between the eye and these instruments, it would not seem entirely unreasonable to suppose,[2] therefore, even in advance of a decisive amount of the evidence which seems to be accumulating, that the visual apparatus consists of receiving and recording parts or levels both of which are necessary to the final response, but either of which may be separately deficient without impairment of the function of the other.

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[1] Griffith, I. (*Phil. Mag.*, 1907, *14*, (6), p. 297) working with ultra-violet radiations and Dember, H. (*Ber. d. kgl. sächs. Akad. d. Wiss.*, 1912, *64*, p. 266) working with the visible spectrum both claim that the photoelectric cell is selective in its response to intensity of light. Elster and Geitel (*Phys. Z.*, 1913, *14*, p. 741; 1914, *15*, p. 610) however, found a constant relation between intensity of light and the response of the cell except in case of very intense light. For a fuller discussion of this point see Ferree and Rand, *Psychological Review Monographs*, 1917, XXXII, (5), p. 46.

[2] It will be understood that an analogy between the eye and the physical recording instruments is attempted here primarily as illustrative rather than as argumentative.

AN ILLUMINATED PERIMETER WITH CAMPIMETER FEATURES.

C. E. Ferree and Gertrude Rand.

BRYN MAWR COLLEGE.

After discussion of the conditions to be met in designing an accurate and serviceable instrument both as to illumination, background, steadiness of eye and fixation, the instrument worked out is here described and illustrated.

This apparatus was devised in response to a request from a committee appointed by the American Ophthalmological Society to work out a better standardization of the illumination of perimeters and test charts. The request was for a feasible means of illuminating the perimeter arm with light of a good intensity and quality, so that every point on the arm in any meridian in which it may be placed shall receive equal intensities of light. Intensity and quality of illumination, however, are only two of the factors which influence the results of the perimetric determination. In devising the instrument described in this paper, it has been our purpose to provide a control also of other factors which are of importance to the work of the office and clinic. The perimeter devised and to be described in this paper has been adopted by the Committee as the standard instrument for office and clinic work.

The variable factors which influence the apparent limits of color sensitivity are, so far as we have been able to discover, the wave length and purity of the stimulus, the intensity of the stimulus and the visual angle, length of exposure of the eye, the method of exposure (moving or stationary stimulus), accuracy and steadiness of fixation, the intensity of the general illumination of the retina and its state of adaptation, breadth of pupil, and the brightness of the preexposure and of the background or surrounding field. The most important of these from the standpoint of the office or clinic are perhaps the intensity of the stimulus, the brightness of the preexposure and the surrounding field, the intensity of the general illumination, and the accuracy and steadiness of fixation.

Perhaps errors in refraction should be included in the above list of factors. They differ from those factors, however, in that they are a source only, or mainly at least, of differences in breadth of field between observers, not for the same observer at different times. They are not therefore a serious source of trouble in the use of perimetry to check up the advance or recession of a given pathologic condition, but they are confusing in diagnosis. We have no certain means of telling, for example, how much of the results in any given case of high myopia is due to the refractive condition and how much if any is pathologic. To add to our knowledge on this point we are now conducting an investigation to determine the effect of various amounts and kinds of refractive errors on the results of field taking. We can not help but feel, as is stated and discussed in the paper, that a provision should be made in our practice of field taking to include one set of results under the correcting glasses, even tho it means either working under conditions which give a narrow field or being content with results which do not include the wider portions of the temporal field.

(1) *Intensity of stimulus.* By a sufficiently wide variation of this factor alone, the zones of color sensitivity may be made to have almost any breadth within the limits of the field of vision, to differ radically in shape, and even to change or reverse their order of ranking as to breadth. When pigment surfaces are used as stimuli, the illumination of the perimeter arm determines the intensity of the stimulus light. Two methods are proposed for securing an even illumination of the stimulus at every point on the perimeter arm and of reproducing this illumination from time to time.

Method 1. When the source of light is inlaid in the surface of the arm or its continuation, the illumination on this surface will be equal for approxi-

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mately 180° on either side of the source. The value of this illumination at every point will be equal to the normal flux of light from the luminous surface divided by four times the square of the radius of curvature of the perimeter arm, or four times the square of the distance of the eye from the perimeter arm. A perimeter embodying this principle of illumination is being constructed in the following way. A lamp house is fastened on the continuation of a 90° arm in such a position that an opening in its surface facing the observer lies in the continuation of the surface of the perimeter arm. This opening is filled in with diffusing glass bent to take the curvature of the arm, and shaded in such a way as to shield the eye of the physician and the observer without changing or interfering with the distribution of light to the perimeter arm. The lamp house rotates with the arm and thus illuminates it uniformly at every point in all meridians.

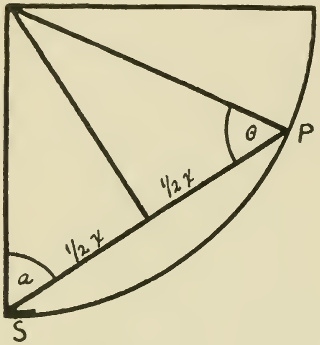

Fig. 1.—Demonstration of even illumination of perimeter arm.

The principle by which an even illumination of the perimeter arm is secured by this method may be demonstrated as follows: Let S, Fig. 1, be the source of light inlaid in the surface of the arm; P any point on the perimeter arm that is to be illuminated; X the distance from S to P; *y* the radius of curvature of the arm or the distance of the eye from the arm; *a* the angle of emission of the light from the source of S; and θ the angle of incidence of this light at the point P. Then the intensity at P will be inversely as the square of the distance of P from S or inversely as the square of X, and directly as the cosine of the angle of emission *a*, $\frac{\frac{1}{2}x^2}{y}$, and of the angle of incidence θ, also $\frac{\frac{1}{2}x^2}{y}$. That is,

$$I_1 = I \times \frac{1}{x^2} \times \frac{\frac{1}{2}x}{y} \times \frac{\frac{1}{2}x}{y} = I\,\frac{\frac{1}{4}x^2}{x^2y^2} = \frac{I}{4y^2}$$

in which I_1 is the intensity of light at P and I the intensity at S. From this equation is derived the law of illumination of the arm: the intensity of light at any point on the arm is equal to the normal flux of light from the source divided by four times the square of the radius of curvature of the arm.

The method has the following objections. (1) The difficulties in construction are not easy to overcome. (2) Evenness of illumination requires an approximately perfectly diffusing glass. This glass is difficult to obtain and prepare and its transmission is apt to be low. Moreover the light incident on the perimeter arm should approximate daylight in composition. The selective absorption required to correct the light from the lamp to this composition further reduces the intensity enormously. This double loss, first by absorption, and second by the somewhat wasteful type of distribution employed, renders it difficult to get an adequate intensity of illumination of the perimeter arm.

Method 2. When the source of light lies in the perpendicular to the plane of the perimeter arm at its center of curvature, it will be equidistant from every point on the arm; also the angles of emission and incidence of the beam of light will be equal for every point on the arm. A perimeter has been constructed embodying this principle of illumination. This perimeter is shown in Figs. 2-5. Two arcs of the same radius of curvature were constructed at right angles to each other; one a 180° arc, the perimeter arm; the other a 90° arc, the lamp arm, at the end of which is placed the source of light. In order that the source of light shall sustain a fixed relation to the perimeter arm for all positions of that arm, the two arms are fastened together at the center of rotation. About the source is a housing which was designed in such a way as to shield the eye of the patient and the physician without interfering with the distribution of light to the perimeter arm. This housing is made of black japanned iron and is painted a mat black on the inside in order that as nearly as possible all of the light which passes to the perimeter arm shall radiate directly from the lamp filament. Its dimensions are 4¼x4¼x5 in. A rectangular aperture 2⅛ in. wide was cut out of the side of the housing facing the perimeter arm, at the bottom and for 3 in. back on the two adjacent sides. The relation of the lamp to the aperture of this housing is such that the light radiates freely without shadows from the filament to every point on the perimeter arm. In order that the lamp may be removed when desired, the bottom of the housing is hinged at the back and is held in place by a latch on either side. To prevent overheating, the housing is well ventilated by especially designed light-tight ventilators, four in the sloping roof of the lamp house and four on each of the sides at the bottom.

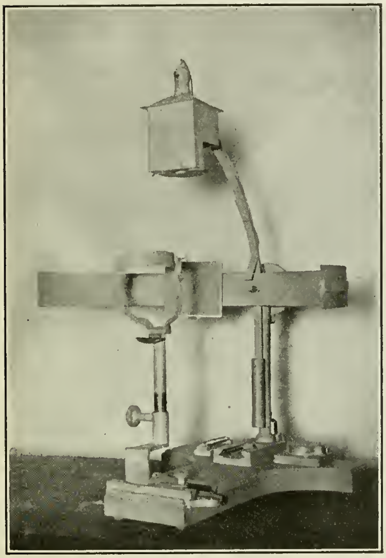

Fig. 2.—Perimeter with illuminating lamp above and target upon the arc.

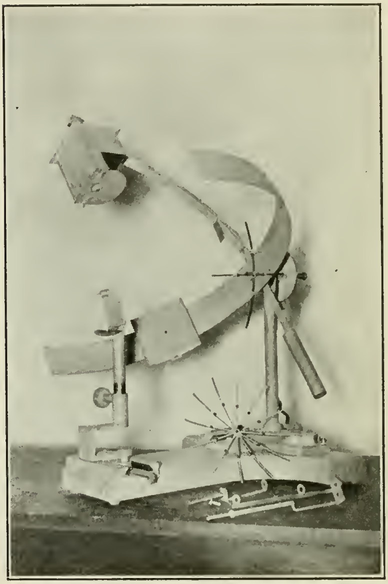

Fig. 3.—Perimeter with arc and lamp swung obliquely. Arms for mapping central scotoma and sights detached.

Provisions are made in the construction of the lamp house for filtering the light to daylight quality. This is accomplished in two ways. (a) A well seasoned 75 watt type C_2 (blue bulb) Mazda lamp operated by ammeter and rheostat control is used as the source of light. This is the ordinary blue bulb commercial lamp and gives only approximate daylight quality. The surface of the bulb is acid-etched to diffuse the light. The intensity of light incident on the perimeter arm when this lamp is used as source of light is 17 foot-candles. (b) A type C (clear bulb) Mazda lamp of 75, 100 or 150 watts depending upon the intensity of light desired, is used as the source. The light from the lamp is filtered to daylight quality by means of a double-etched collar or cylinder of carefully prepared daylight glass 2½ in. broad and 4 in. in diameter, which can be inserted into the bottom of the lamphouse so as to fill completely the three-sided aperture. When in position all of the light emitted from this lamp house must pass thru the filter. The collar is securely held in position by three pins so placed in the bottom of the lamp house as to form the apices of an equilateral triangle of the appropriate dimensions. This bottom is hinged so that it can be dropped down for the insertion of the collar and is provided with latches, so that it can be held securely in position when raised. The light of a type C Mazda lamp filtered by this glass is a very close spectrophotometric approximation to north skylight. The coefficient of transmission of the glass is 15 percent. The light incident thru the filter on the perimeter arm from a 100 watt type C Mazda lamp has a value of 2.6 foot-candles, an intensity very suitable for the taking of a low illumination field, the importance of which in diagnosis will be discussed later. Higher intensity fields may be obtained by using higher wattage lamps.

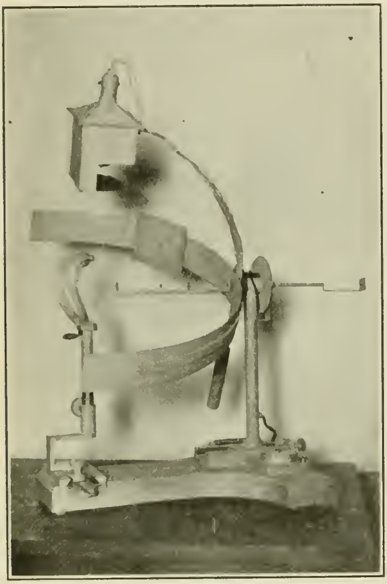

Fig. 4.—Side view of perimeter with attachments in place.

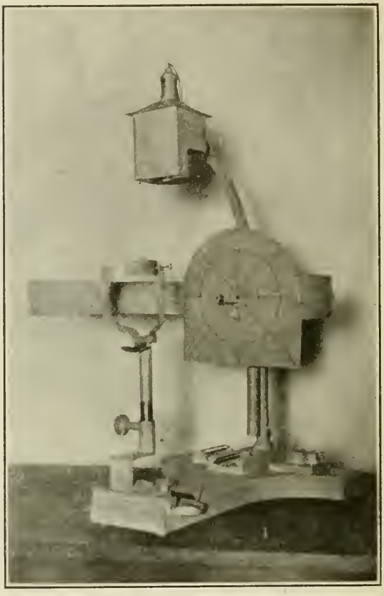

Fig. 5.—Oblique view of perimeter, showing campimeter field and sight in place.

This perimeter is not difficult to construct or to operate. It provides for a uniform illumination of the perimeter arm in all meridians with light of a good intensity and quality; and with it a precision of control is possible which is comparable with the work of the physical laboratory. Of the two instruments we have devised, it is without doubt much the more feasible, and it is also very probably the more correct in actual practice. Both instruments are correct in theory.

(2) *The brightness of the preexposure and the surrounding field.* The brightness of the surface to which the eye is preexposed may change the apparent limits in certain meridians as

much as 17-20°. A preexposure lighter than the color gives a dark, and one darker than the color a light after image. These after images change profoundly the saturation of the color sensation, also its hue. A background or surrounding field lighter or darker than the color produces a similar effect on the limits, but not so great. In this case the disturbing achromatic effect is due to physiologic induction or contrast. The variable effect of brightness of preexposure and surrounding field can be eliminated only by making both a gray of the same brightness as the stimulus color. Here again a precise control of the intensity of the illumination for all points on the perimeter arm becomes important. That is, the shade of gray which is needed to match the color in brightness changes with change of illumination; therefore, the selection of a gray which will match the color in brightness for all points of work presupposes constancy and uniformity of illumination. A further advantage is gained by making the background of the same brightness, as the color. That is, when color and background are of the same brightness the stimulus disappears completely when the limit of sensitivity to that color is reached, instead of turning into a gray, concerning the colorlessness of which the patient is apt to be in doubt. This gives the effect of the disappearance type of photometer and like it adds greatly to the ease and certainty of making the judgment.

The control of brightness of preexposure and surrounding field is provided for in the following way. To the stimulus carriage is attached a light aluminum holder, No. 19 B & S gauge, grooved to hold a card 5x6 in. These cards are covered on one side respectively by grays of the brightness of the four colors, red, yellow, green and blue of the Hering standard series of pigment papers, as seen in the peripheral retina. At the center of each of these cards is pasted a disc of the appropriate color subtending a visual angle of 1°. To provide for the control of the preexposure for the stationary method of giving the stimulation, cards identical with the background cards are provided, covered also on one side with a gray of the brightness of the color. The stimulation by this method is given as follows: The stimulus is placed at the point to be tested and covered with the preexposure card. The observer is told to take his fixation. At a given signal the stimulus is uncovered for one second and recovered. In case the moving stimulus method is used, the surrounding field serves as the preexposure.

The perimeter arm and body are painted a gray of a shade which is approximately mid-gray to the blue and yellow, the darkest and lightest of the stimuli employed. In our own laboratory the perimeter is used on a table painted with the same gray and stands before a gray screen. These latter precautions, however, are not necessary.

When the instrument is supplied to the profession, provision will be made that the stimulus and preexposure cards, a seasoned lamp, and all other perishable parts can be furnished in the quantities desired.

(3) *The accuracy and steadiness of fixation.* All are familiar with the disturbing effect of inaccuracy and unsteadiness of fixation. If correct and reproducible results are to be obtained, the eye must be accurately placed at the center of the sphere in the surface of which the perimeter arm lies, and the line of sight must not shift from the fixation point while the color observation is being made. As an aid to the correct placement of the eye and a check on its steadiness of fixation, two devices have been provided. (a) A small circular mirror is used as a fixation object in which the observer sees the image of his own eye (Fig. 2). When the eye is correctly placed with the line of sight normal to the surface of the mirror at its central point, the fact is indicated to the observer by the position of the image of his pupil and iris as seen in the mirror. Not only is this simple device of service in determining the correct position of the eye, but it aids the observer greatly in holding a steady fixation.

We scarcely need to point out that a fixation object does not afford an accurate control of fixation. Exact checking methods show that the patient is not always fixating the object when he thinks he is. The only guide to monocular fixation is clearness of seeing, and this is a criterion that presents considerable latitude. However with a mirror, the patient has an objective check on the position of his eye.

One of the objections to the use of a mirror as a means of controlling fixation is the likelihood of glare from its surface, probably due to a combined specular and diffuse reflection rendering, in proportion as it occurs, the clear seeing of the image of the eye by the patient unnecessarily difficult. This objection has been obviated in the instrument described by cutting off the direct radiations from the lamp from the mirror by a narrow shield, which can be turned back out of the way when not in use. With the shield in position the eye receives from the mirror only the light which is first reflected from the eye to the mirror and then back to the eye. The device adds greatly to the ease and clearness with which the patient sees his imaged eye. The elimination of the troublesome glare on the surface of the mirror is rendered particularly simple and easy in case of this instrument because of the plan of illumination employed, *i. e.,* the light all comes from a fixed source above and directly in front of the mirror. If the perimeter were illuminated from a window, for example, and its position with reference to the window changed as is needed in order to give as nearly as possible equal illumination of the stimulus in its various positions, the elimination of glare from the surface of the mirror would not be so simple a problem.

Another theoretic objection to the mirror is that the clear seeing of the iris in the mirror requires the eye to focus for twice its distance from the perimeter arm. When this distance is 33 cm., as in the present case, the use of the mirror as a fixation device throws the refracting system of the eye 1.50 diopters out of focus for the colored stimulus on the perimeter arm. Just how important this is when the problem is the mapping of the limits of color sensitivity and not a determination of acuity is difficult to say *a priori.* The poor imaging for the peripheral field is well known to all who have made determinations of acuity at points far removed from the center of the field. The additional blurring due to an error of focussing of the magnitude described is probably of negligible consequence at points having an excentricity of 30—70 degrees, particularly in determinations of color sensitivity. In any event, we have not been able to detect appreciable differences in the limits of sensitivity at 17 foot-candles of illumination with the mirror as a fixation device and with the other device provided, in a case where the eye is correctly focussed for clear seeing at 33 cm.

(b) The second device for the control of fixation is similar in principle to a peep-sight and may be called a parallax or peep-sight device (Fig. 5). A small disc or button (8 mm. in diameter) at the center of rotation of the perimeter arm is viewed thru a circular opening (7 mm. in diameter) in a thin round metal disc 9 cm. nearer to the eye. The plane of the disc and the viewing opening are both normal to the line of sight when the eye has its correct position and fixation. When the eye has this position and fixation, the relation of size of disc and opening is such that the disc is seen not quite to fill the opening. The disc is painted black, also the edge of the opening; thus when the eye has the proper position and fixation, the edge of the opening is seen concentric to the disc, with a narrow ring of the gray of the brightness of the perimeter arm between. The control afforded by this device is very sensitive. A very slight deviation of the position or fixation of the eye results in the complete or partial extinction of this ring at a point in the direction of the deviation. Like the mirror the device is mounted on a short pin or plug which can be inserted in the fixed tubular axle about which the perimeter arm rotates.

However, while the image in the mirror or the correct sighting of the fixation disc thru its opening will indicate to the observer when the line of sight is normal to the surface of the fixation object at its central point, there are two important features in the correct adjustment of the eye over which these devices exercise no control: (a) the distance of the eye from the mirror; and (b) the agreement of the meridians of the field of vision as read on the perimeter with the meridians of the retina. In order that it may be known when the eye is at the correct distance from the perimeter arm, a light measuring rod 33 cm. in length is provided, to one end of which is fastened at right angles a small metal disc. In making the adjustment for distance one end of the rod is placed against the mirror at its center and the distance of the perimeter from the observer's eye is changed by means of the coarse screw adjustment to be described later, until the closed lid is just in contact with the metal disc.

Perhaps the simplest device for ensuring a constancy of relation of the meridians of the retina to the meridians of the field of vision as laid off by the perimeter arm, in other words for guarding against a slight tilting of the head to one side or the other, is a mouth bit. We have designed (Fig. 3) a very small and unobjectionable mouth bit of light wood to be changed for each observer, so shaped that it can not be bitten too far forward or back, and thus the distance of the eye from the mirror be changed, or too far to one side or the other. There seems, however, to be an insuperable prejudice against the use of a mouth bit by both the physician and the patient. We have designed, therefore (Figs. 2, 4 and 5) a head rest which follows approximately the outlines of the forehead, side of the head and face, furnished with a suitably cupped chin rest, the height of which is adjustable, also its position forward or backward. To provide for individual differences in shape and breadth of forehead, an adjustable forehead piece or band of thin spring steel extending well around to the side of the head is screwed at its central point to the forehead piece of the head rest. This forehead band is adjusted to fit foreheads of different shape and breadth by means of a set screw on either side near the two ends of the band. When the chin rest is adjusted to its proper height and the forehead band is made to fit the forehead, the patient's head is held comfortably in position and sufficiently rigid, it is believed, to satisfy the needs of office and clinic work. At least the probability of tilting the head to one side or the other, thus causing a disagreement of the meridians of the field of vision as indicated by the perimeter readings with the meridians of the retina is very greatly lessened, if not entirely obviated. This, it will be remembered, is the especial purpose of the device, the other features of the control being taken care of in other ways.

In order quickly and conveniently to locate the patient's eye at the center of the perimeter system, three adjustments are provided; a rack and pinion to raise and lower the head, a second rack and pinion to shift the head to right or left, and a coarse screw adjustment to change the distance of the perimeter arm from the eye. In the process of getting the eye in position, the patient bites the mouth bit or adjusts the head in the head rest, brings the eye to the level of the fixation device (mirror or peep-sight) with the first rack and pinion, and centers its image in the mirror with the second rack and pinion. The physician gets the correct distance of the perimeter arm from the patient's eye by means of the screw adjustment and the measuring rod already referred to. Once these adjustments are made for an eye, they need not be made again during the process of taking the fields for that eye; that is, the biting of the mouth bit or the return of the head to the head rest guarantees that the eye always returns to the same position for which the original adjustments were made.

A very great practical need in a clinic perimeter is a method of controlling fixation for patients who have a central scotoma or pathologic blind area. With the eye properly adjusted for taking the fields, these patients are not able to see a central fixation object. A device has been constructed (Fig. 3) for controlling the fixation of such patients in the following way. The perimeter arm is made to rotate about a hollow fixed axle. Into this fixed axle telescopes the stem at the end of which is the mirror or peep-sight used for patients with normal or approximately normal central vision, also a hollow stem carrying the device used to control the fixation of patients with a central deficiency. This latter device consists of four light arms or rods at right angles to each other curved to follow the arc of the perimeter arm, and of sufficient length to provide for all probable breadths of scotoma. Each of these arms carries a small stimulus the distance of which from the center of the field is adjustable. In adjusting the patient's eye by this device, the physician looks thru a small telescope contained in the hollow tubular axle and lines up the pupil of the patient's eye with the cross hair in the field of the telescope. When the patient's eye is observed to be in position, two or all four of the stimuli as may be desired are adjusted so that they can just be seen by the patient at the edges of the scotoma. These stimuli serve as the control of the patient's fixation, his instructions being to direct the eye so that all are visible.

This fixation device intended to control the fixation during the taking of the fields can be made serviceable for mapping the scotoma itself by adding 12 or more graduated arms equally spaced, making 16 in all, provided with stimuli similar to those already described. Then when the fixation is obtained by the adjustment of the four stimuli designed for that purpose, the further mapping of the scotoma is accomplished by moving the remaining 12 until they are on the edges of the scotoma. Or if desired the four stimuli designed for the control of the fixation may not be used for that purpose at all. The physician may watch the patient's eye thru the telescope directing the fixation by means of the cross hairs, while all of the stimuli are moved into position on the edges of the blind area. This objective control of the fixation may also be used, both in mapping the scotoma and in taking the fields when a central scotoma is present.

If desired the patient's eye can be rendered more visible by reflecting the light from the lamp directly on to it. This is provided for by placing a small oblong mirror of specular metal on the lamp arm at such a position and angle that the light received from the lamp will be reflected on to the iris. This mirror is hinged to the lamp arm and can be turned back against it when not in use. The hinge is provided with a stop so that when the mirror is turned down it can not go beyond the position required to reflect the light on to the eye. The visibility of the eye in the field of the telescope is considerably increased also by excluding as far as possible scattered light. This was done by putting the objective lens well back in the tube, painting the inside of the tube a mat black and placing on the end of the tube nearer the eye a short tubular hood, which shields the opening from the direct rays from the lamp and admits only those reflected from the eye.

Another important need in a clinic perimeter is a method of giving the correct location and fixation to eyes suffering with high myopia. Eyes with myopia ranging from 8-20 diopters would have great difficulty in seeing a fixation object at a distance of 33 cm. Because of the grave pathologic changes which take place in the retina and choroid of eyes suffering from high myopia, particularly in the region of the macula and nerve head, it is of great importance to be able to use both the perimeter and the tangent screen to be described later, in the examination of eyes in the more advanced stages of myopia. Three provisions have been made for this. (1) The mirror may be mounted on a rod sufficiently long to permit of its location at any point in the line of sight between the perimeter arm and the eye. This rod may be inserted in the tubular axle on which the perimeter arm rotates. (2) A peep-sight device is provided similar in principle to the one already described, and so constructed that it may suffice as a fixation control for values of myopia ranging between 8 and 20 diopters. As shown in Fig. 4, this device has been so constructed that it can be used either for the normal or the myopic eye. That is, it is provided with two sets of fixation targets and viewing openings, each at their proper distance from the eye. Both sets are hinged to the narrow steel bar which serves as their support, so that either can be turned down out of the way when not in use. The diameter of the target for use with the normal eye is 8 mm.; the diameter of the viewing opening, 7 mm.; and the distance of the opening from the target, 9 cm. The diameter of the target for use with the myopic eye is 8 mm.; its distance from the perimeter arm is 16 cm. The diameter of the viewing opening is 6 mm. and its distance from the target is 9.5 cm. (3) The perimeter arm may be illuminated with two intensities of light; one carrying the fields well towards the periphery of the retina, the other giving limits narrow enough to fall within the corrected field of the glasses which are worn or may be worn by the patient. This feature provides also for the correction of high astigmatisms, the presence of which make field taking annoying and uncertain as a diagnostic procedure. There are other advantages too of providing for the taking of fields at more than one intensity of illumination. (a) Because of the concentric arrangement of the fibers in the nerve trunk and their order of distribution in the retina, it may be of importance as a point of diagnosis to sample the responses of the retina at different degrees of excentricity. And (b) the low illumination fields are in general more sensitive to the influence of the pathologic factors which cause the fields to have different breadths. This is largely due to the fact that low illumination fields are narrow fields. That is, sensitivity falls off gradually near the center of the retina, therefore smaller changes of sensitivity are required near the center of the retina to expand or contract the field. It is probably also due in part to the change produced in the state of the retina's sensitivity at low illumination.

The control of fixation for the presbyopic eye also presents a problem to the perimetrist. The eye with a high degree of presbyopia would have considerable difficulty in seeing with the necessary clearness a fixation object at a distance of 33 cm. By the use of the mirror as fixation control this distance is extended to 66 cm. The satisfactory use of the mirror requires that the image of the eye be seen fairly clearly, and an eye without power of accommodation even if there is no hyperopia for far seeing is approximately 1.50 diopters out of focus for an object at a distance of 66 cm. When 1.50 diopters out of focus the eye can not see its image in the mirror with a satisfactory degree of clearness. However, the mirror can be used with a fair degree of satisfaction for lesser degrees of presbyopia.

We have three proposals to make for the control of fixation for the presbyopic eye. (1) The use of the mirror for the lesser degrees of presbyopia. (2) The use of an illumination sufficiently low to bring the color fields within the field of the correcting glasses. And (3) the use of a peep-sight or parallax fixation device (Figs. 3 and 4)[1] similar in principle to the one already described, with the target at a distance great enough to be seen with the necessary degree of clearness by the eye without power of accommodation. Sixty-six cm. has been chosen for this distance because (a) the target can be seen at 66 cm. with sufficient clearness to determine whether or not it is at the center of the viewing opening even tho the eye is as much as 1.50 diopters out of focus; and (b) a greater distance presents difficulty as a matter of feasibility of construction. The device is provided also with a lens, the distance of which from the target can be varied from its focal length to that which is needed to render the target clearly visible with 3 or more diopters of accommodation. (Three diopters are needed for the perimeter arm). With this lens at its focal length from the target, the rays of light are rendered parallel and the apparent or optical distance of the target is 6 meters. By suitably changing the distance of the lens from the target, the apparent distance of the target can be varied over a wide range. By means of this optical device, therefore, a clear image of the target can be formed on the retina of patients having all degrees of presbyopia with as little disturbance of focus for the perimeter arm for each degree of presbyopia as is possible for that amount of presbyopia. However, as we have already stated, it is quite possible to secure a good control of fixation without the use of the optical attachment.

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[1] As already stated, the device for control of fixation in high degrees of myopia is also shown in Fig. 3 in position for use. When using either, the other should of course be removed.

The fixation device consists of a tube 17.5 cm. long and 8 mm. in diameter, and a light metal rod fastened at one end of the tube and supporting vertically at the other a small plate of hard sheet aluminum 3x3 cm., at the center of which is a disc 4 mm. in diameter. This disc and plate serves as the fixation target. To use this device as a control of fixation the telescope is removed from the tubular axle of the perimeter and the tube of the fixation device is inserted in the axle to a depth of 4.5 cm. To control the depth of this insertion and thus the distance of the target from the eye, the tube is provided with a stop or shoulder 4.5 cm. from the end inserted. The tubular axle and its extension thus form the opening thru which the fixation target is viewed, and when the eye is in position at the center of the perimeter system the target is seen to be centrally located in this opening. The target itself is painted black and the plate at the center of which it is mounted is painted in the same shade of gray as the remainder of the perimeter. The target receives its illumination from the lamp which illuminates the perimeter arm. An unobstructed passage of light from the lamp to the target is possible because of the distance of the target 33 cm. behind the perimeter arm. The lens which is used to vary the optical distance of the target from the eye is mounted in the end of the main tube, facing the target. This tube telescopes to the desired depth into a shorter tube, at the end of which on a short supporting rod is the target.

The steadiness of fixation is greatly influenced by the method of giving the stimulation. One of the serious objections to a moving stimulus is the difficulty of holding a steady fixation while the object to be observed is moving. The alternative procedure is the use of a stationary stimulus. That is, the stimulus is placed at the desired point on the perimeter arm and covered with the pre-exposure card. The observer takes his fixation and at a given signal the stimulus is exposed and recovered. By this method of giving the stimulation more time is consumed, but a much greater precision of result is possible. A compromise procedure is recommended. That is, the approximate location of the limit is determined with the moving stimulus, and the exact location with the stationary stimulus. By this compromise but very little more time is required, and there is no sacrifice of precision.

In order to provide for the mapping of the normal blind spot and for the quick detection and mapping of central and paracentral scotomata, it has been deemed advisable to add to the perimeter a tangent screen subtending a visual angle of 60 or more degrees. Provision is made so that this screen can be quickly and conveniently attached to the stimulus carriage and moved into position. The stimulus carriage and the tangent screen have at their exact center a circular opening equal in size to the cross section of the tubular aperture about which the perimeter arm rotates. Thus when the tangent screen is in position, *i. e.,* with its central point in the axis of rotation of the perimeter arm, the tubular opening in the perimeter is continued thru to the front surface of the tangent screen. This both provides for the exact adjustment of the tangent screen and permits of the convenient use with it of all of the fixation controls which we have described. Cards of white or black as may be desired, with the fields laid off on the tangent scale, are provided for the mapping of the area deficient in the light sense, and of grays of the brightness of the colors for mapping the color deficiencies. This is shown in Fig. 5. It is quite possible that the stimulus and pre-exposure cards used for the field taking and the larger backgrounds or cards for the tangent screen could be made of thin hard sheet aluminum coated with a flat enamel paint of white, black or grays of the brightness of the colors. If this were done, they could be kept clean by washing and the small paper disc of pigment color used as the stimulus for the field taking is all that would have to be renewed as the result of long periods of use. These paints can be bought in a flat black and a flat white. By using the two in the desired proportions the shades of gray desired may be obtained.

In our own work we have found it convenient to use the large screen just described for a quick survey of the field for scotomata, and a smaller screen, similar to the one used to carry the colored stimulus in the field taking, for the actual detailed mapping of the scotomata and the normal blind spot. This screen was made considerably larger than the screens which serve as backgrounds for the colored stimulus in field taking in order that it might serve for the mapping of large scotomata and pathologically enlarged blind spots. It is mounted in a carriage of its own and is shaped to take the curvature of the perimeter arm. This screen is intended not as a substitute for the larger screen, but as a supplement in cases in which such a supplement is found to be convenient and desirable. This device has the following advantages over the large central tangent screen for the actual mapping of the blind areas. (1) It can be moved to any part of the field from the center out to 90° in any meridian and its center located at the center of the area to be mapped. When the screen is properly centered the mapping can be done as it is on any tangent screen. (2) Upon each screen is drawn 16 meridians running radially from the center of the screen. These meridians are finely graduated so that the limits of sensitivity in any meridian can be read off for the permanent record and transferred to properly planned maps at the convenience of the experimenter. (3) Blind areas are most easily and precisely mapped when the stimulus is made to follow lines radiating from the center of the area. Unless there are such guiding lines, it is difficult to pass from within out or from without in consistently when determining the limits of the blind area, or when checking up the location of a limit by a second or third determination. On a large fixed screen these lines would have to be drawn specially for each scotoma. (4) All of the evidence points toward the importance of mapping the blind areas with colored stimuli, particularly the Mariotte spot. It is highly important that the determinations for the different colors be made on backgrounds of the same brightness as the colors, as will be shown by blind spot studies to be published later. It is much more feasible to arrange for this in case of the smaller movable fields than in case of a large fixed field. When the background for the smaller field is laid off in graduated radial lines, it can serve for the mapping of many blind spots and scotoma before it need be replaced. In case of a large fixed screen, this superior adaptability and long service would not be possible. (5) With the movable smaller field, it is more nearly possible to map all blind areas under the conditions of equal illumination which obtains in the perimetry of the color fields, than it is in the use of the large fixed screen. In the latter case the illumination at which the mapping is done in one part of the field, may be quite appreciably different from that at which it is done in another part, of the field. The control of illumination while not so important for mapping the blind areas to the light sense stimuli, is very important in the mapping of the blind areas to colors.

With the controls provided in the perimeter recommended, a careful worker can without difficulty reproduce the limits of sensitivity within 1 or 2 degrees.

PERIMETRY: VARIABLE FACTORS INFLUENCING THE BREADTH OF THE COLOR FIELDS.

Prof. C. E. Ferree and Gertrude Rand, Ph.D.

BRYN MAWR, PA.

This is the first of a series of papers upon perimetry, and deals particularly with the factors upon which thresholds of light and color perception depend. It calls attention to the irregularities of color sensitivity for different colors and for different meridians of the visual field.

The difficulty of getting reproducible results in determinations of the color sensitivity of the peripheral retina is a common complaint among laboratory and clinic workers. The actual distribution of retinal sensitivities is only one of the factors which influence the results of the perimetric or campimetric determination. By varying the conditions under which the work is done, the zones of color sensitivity may be made to have almost any extent within the field of vision, to vary radically in shape, and even to reverse their order of ranking as to breadth.

The difficulty of obtaining reproducible results is so great as to lead many seriously to question the value of the perimetric or campimetric determination in the work of diagnosis. Their value in diagnosing and checking up the course of some of the most serious affections of the eye is readily conceded, however, provided the needed precision can be obtained. The need of greater precision of work in the laboratory, while less important to human welfare, is no less insistent. These combined needs led us several years ago to make a study of the variable factors which influence the chromatic response, the details of which study are still in progress. Some of these factors pertain to the stimulus; some are peculiar to the response of the eye itself. All may be standardized and controlled. The normal eye is highly sensitive and complex in its responses, but not inherently erratic. While the abnormal eye may be more erratic—one of the symptoms, it may be, of its abnormality—there should be, so far as we can see, no essential difference in the technic of testing and studying its functions.

The theory and practice of clinic field taking seems up to the present time to have been based on the following assumptions: (1) The far periphery of the retina is blind to color, that is, there are definite limits or boundaries of the sensitivity to colored light. These may be called the *actual* limits of sensitivity. The limits as determined, the apparent limits, may or may not agree with the actual limits, depending upon the conditions under which the work is done. (2) The factors affecting the apparent limits of sensitivity, when the fields are taken with pigment colors, are the size and the coefficient of reflection of the stimuli employed. A contraction of the fields, taken under standard conditions of control for these two factors, means then an actual change in the distribution of sensitivities. (3) Sensitivity decreases from the center towards the periphery of the retina, in a fairly regular manner in any given meridian, and the rate of decrease for the same color is approximately uniform from meridian to meridian over a considerable range near the limits of sensitivity. Irregularity of contraction, resulting in a change in the shape of the field, is not therefore to be expected as a phenomenon of the normal eye. And (4) the field of sensitivity is wider for blue than for red. The limits of the fields should not then be expected to interlace, or to reverse their order of ranking as to breadth, without some pathologic or other disturbance in the distribution of sensitivities.

A study of the distribution of sensitivities in the peripheral retina and the factors which affect the apparent limits of sensitivity, shows that these assumptions are not correct. The far periphery of the retina is not blind to blue and red, nor is the sensitivity in this part of the retina greater for blue than for red; the decrease of sensitivity from the center towards the periphery of the retina is very irregular in any given meridian, and the rate of

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decrease is very different from point to point in the different meridians; the apparent limits of sensitivity are a function not of two but of several variables. All of the field changes noted above as pathologic may occur, and do occur, as the result of nothing more serious than a defective control of the variable factors which affect the sensitivity of the peripheral retina to color.

The variable factors which affect the sensitivity of the peripheral retina to color, and therefore the results of field taking are, so far as we have been able to discover, the wave length and purity of the stimulus, the intensity of the stimulus and the visual angle, length of exposure of the eye, the method of exposure (moving or stationary stimulus), accuracy and steadiness of fixation, the intensity of the general illumination of the retina and its state of adaptation, breadth of pupil, and the brightness of the preexposure and of the background or surrounding field. Only a few of these can be considered in the present series of papers. For the fuller treatment a bibliography is appended. The most important of these factors from the standpoint of the work of the office and clinic are the intensity of the stimulus and the precision of its control, the brightness of the preexposure and of the surrounding field, the intensity of the general illumination, and the accuracy and steadiness of fixation.

In the present paper, the effect of variations in the intensity of the stimulus alone will be discussed. The discussion of the effect of other factors will be given in later papers. Obviously, the effect of any uniformly acting factor on the size and shape of the color fields and their order of ranking as to breadth will depend upon the type of distribution of sensitivities in the peripheral retina. The first step toward an understanding of the normal color fields and their variations under the influence of different conditions of work, therefore, is a study of the distribution of sensitivity in the peripheral retina of the normal eye. Results will be given illustrative of this distribution, and the effect of variations of intensity on the normal color fields will be discussed and explained in terms of these results. In making this selection of a factor, intensity is regarded as typical. That is, whatever is true of the effect of intensity should be, true, also in a general way, of the effect of any other uniformly acting factor which produces large variations in the breadth of the color fields.

THE INTENSITY OF THE STIMULUS.

By a sufficiently wide variation of this factor alone, the fields of color sensitivity may be made to have almost any breadth in the field of vision, to differ radically in shape, and even to change or reverse their order of ranking as to breadth,—changes of a type and magnitude to which the clinician might ascribe a grave and important pathologic significance. For example, with very high intensities of stimulus the limits of red, yellow and blue are coincident with the limits of white light vision. Green can not be made to have so wide an extent. With stimuli of medium intensity, and of the relative energies found in the prismatic spectrum of a Nernst filament, the limits are concentric and in the order from widest to narrowest of red, yellow, blue and green. With stimuli of medium intensities of equal energy (equal physical intensities) the limits of red, yellow and blue interlace or crisscross. The limits for green again are narrower. The limits for pigment stimuli may be either interlacing or concentric in the order from widest to narrowest of red, blue and green; or blue, red and green, depending upon the pigments used and the intensity of light falling upon the perimeter arm.

It seems only fair to conclude, therefore, that the conventional clinic rating of the limits from widest to narrowest in the order of blue, red and green is a function of the relative and absolute intensities of the stimuli employed, as well as of the actual distribution of sensitivities. A change in the intensity of the stimulus not only changes the limits but, because of the irregular distribution of sensitivities in the different meridians, causes a marked change in the shape of the fields; and because of changes in the ratio of sensitivity to the different colors in the same meridians, a change in their order of ranking as to breadth. Without great precision in the control of intensity, it is obvious that reproducibility of result can not be obtained, and little significance can be attached to extent or shape of field, to order of ranking as to breadth of field, or to any variations from time to time or from person to person in these important features.

The effect of changes in the intensity of the stimulus both on the extent and shape of the color fields varies with the order of magnitude of intensity employed. For medium and low intensities, the effect of a given amount of change is very much greater than for high intensities. This is an obvious corollary of the type of distribution of sensitivities found in the peripheral retina. That is, in passing from the center towards the periphery, the decrease in sensitivity is comparatively slow and gradual in the paracentral retina; it is much faster and more abrupt in the mid pheriphery; and very abrupt in the far periphery. It requires, therefore, comparatively large changes of intensity in stimuli of high intensity, which carry the limits of sensitivity into the far periphery, to produce a significant change in the limits; not so great a change in the stimuli of medium intensity; and a still smaller change in stimuli of low intensity. This effect varies greatly, however, for the same color in the different meridians, and for different colors in the same meridians. For the stimuli of medium and low intensities used in the office and clinic, the effect of change of intensity is very marked indeed, both on the extent and shape of the fields of sensitivity.

We have stated that the order in which the fields may be found to occur, ranked with regard to breadth, depends upon the actual distribution of sensitivities and upon the relative and absolute intensities of the stimuli employed. That it depends upon the relative intensities should be more or less obvious, provided of course that the relative differences of intensity are great enough to overcome or reverse the actual differences in sensitivity. In support of the statement that it depends also on the absolute intensity, maps will be shown in a later paper in which for the same eye and a constant ratio of intensity of stimuli, the limits for red and blue in some cases interlace or crisscross; in others they are concentric or nearly so—the limits for blue lying outside of the limits for red; or conversely the limits of red lying outside of the limits for blue—the difference in result depending solely upon the absolute intensities of the stimuli employed. The determinations were made with the Hering standard pigment papers presented to the eye by means of the perimeter described in a preceding paper,[1] with the preexposure and surrounding field of the brightness of the color, the only variable being the intensity of illumination of the perimeter arm.

THE CHROMATIC THRESHOLDS OF SENSATION FROM CENTER TO PERIPHERY OF THE RETINA.

As we have already stated, the effect of such factors as intensity on the extent and shape of the color fields and their order of ranking as to breadth can be better understood when a thoro knowledge is had of the actual distribution of sensitivities from point to point from center to periphery of the retina. In order to show this distribution; we have made determinations of the threshold of sensation (the amount of light required just to arouse the color sensation) with spectrum lights and under proper conditions of control, for the different colors at near lying points in the different meridians. A graphic representation of the results of these determinations for two meridians, the temporal and the nasal, is given in Charts 1-4. In these charts the degree of excentricity is plotted along the horizontal coordinate, and the energy or intensity values of the threshold in watts (10^7 ergs per second) are plotted along the vertical coordinate. The values of the thresholds for blue are represented by the continuous line; for yellow by the dotted line; for red by the dash line; and for green by the dash-dot line. In case of red, yellow and blue, it will be remembered from statements made earlier in the paper, the limits of sensitivity for lights of high intensities coincide with the limits of white light vision. This, however, was not the case for the green stimulus. By no increase of intensity were we able to make the limits of green sensitivity coincide with the limits of white light vision.

In charts 3 and 4, the above values from the center of the retina, thru the region of gradual decrease of sensitivity, are plotted on a larger scale, a tenfold amplification. This was done, because when plotted on the scale used in charts 1 and 2, the curves fell so closely together, that the relative sensitivities to the four colors are not clearly represented. This is, the range of values for the threshold from the center to the extreme periphery of the retina is so great, that in charts 1 and 2, in which the entire range is represented, a scale value had to be chosen for the vertical coordinate which is so large as almost to obscure the smaller differences in relative sensitivity to the different colors in the paracentral retina, the region of gradual decrease in sensitivity.

Space can not be taken here for a full discussion of the results of these determinations. For a more detailed statement of results and a fuller discussion of their bearing on points of theoretic and practical importance, the reader is referred elsewhere.[20] The following points, however, may be noted in connection with the present paper:

(1) *The great range of sensitivity from the center to the extreme periphery of the retina.* For example, in the temporal meridian the sensitivity to red is 900 times as great at the center as at the extreme periphery of the retina; for yellow 1650, for blue 3280, and for green 3380 times as great.

(2) *The great irregularity in the decrease of sensitivity* which is found in passing from the center to the periphery of the retina. This irregularity, moreover, differs greatly in the different meridians. From these irregularities, it is obvious why the shape as well as the extent of the fields of sensitivity change with the change of intensity of the stimulus light. That is, depending upon the different rates of decrease of sensitivity in the different meridians, a given increase or decrease of intensity of the stimulus light causes respectively different amounts of extension or contraction of the fields in these meridians. The result is, of course, a change of shape of the field proportionate to the amount of irregularity of the distribution of sensitivity in the different meridians.

A further obvious corollary of the irregularity of distribution of sensitivity in the different meridians is the interlacing or crisscrossing of the limits when the stimuli are so graded in intensity as to give the limits for all the colors approximately the same degree of excentricity. That is, a condition of coincident or concentric limits, would presuppose a regularity of distribution of sensitivity from meridian to meridian; irregularity inevitably leads to an intersection or crisscrossing, when the conditions under which the determinations are made are such that the fields have approximately the same breadth. A frequent crisscrossing of the limits, it will be noted in charts to be given in a later paper, occurs for red, yellow and blue, when stimuli of medium intensity and of anywhere near equal energies are used.

(3) A third point is the great *irregularity in the ratio of sensitivity to the different colors,* which is found in the same meridians in passing from the center to the periphery of the retina. At some points, for example, the sensitivity to red is greater than the sensitivity to blue; at others the reverse is true. An obvious corollary of such shift in relative sensitivity is a reversal of the order of breadth of the color fields, a reversal which we have every reason to believe is not pathologic. This does not mean, of course, that reversals in order of breadth may not be of pathologic origin. It does indicate that they may occur in case of the normal eye, as the result of no more serious condition than a change in the absolute intensity of the stimulus light, or translated into terms of ordinary office and clinic practice, a change in the intensity of light falling on the

perimeter arm at the point of work—a change, moreover, no greater than may occur in the illumination of a daylighted room from noon to four o'clock on any bright winter day. That is, as the intensity of the stimulus light changes, the limits fall at different distances from the center of the retina. If they happen to fall in a region where the sensitivity is greater to red than to blue, the limits for red will be outside the limits for blue; and conversely if they happen to fall in a region where the sensitivity to blue is greater than to red, the limits for blue will lie outside of the limits for red. There is no reason to believe that these irregularities are the same in kind or degree from person to person. Obviously, the only safeguard against misinterpretation either in establishing a norm or in making comparisons with an established norm, is always to work with the same conditions of control. A difference in result will then mean an actual difference in sensitivity or in the relative distribution of sensitivities, as the case may be. Working under these conditions, we have a chance really to find out what is normal with regard to the breadth and shape of the fields of sensitivity, and their relations for the different colors, and to check up their variations from time to time as the result of the advance or recession of a pathologic condition.

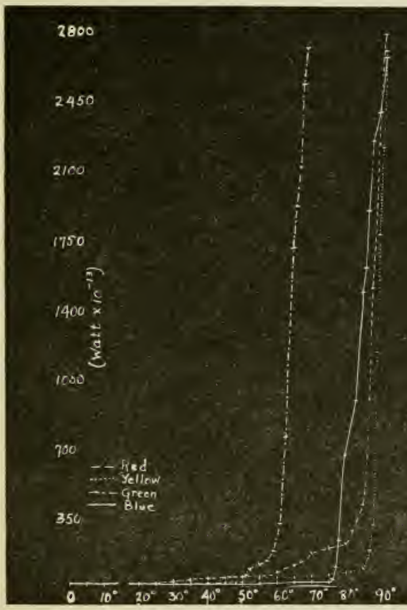

Chart 1. Chromatic thresholds for the four colors, temporal meridians.

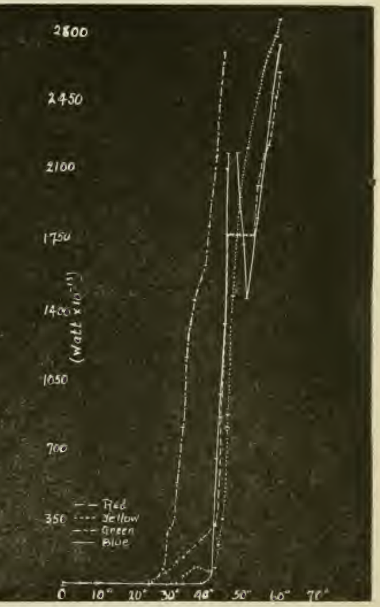

Chart 2. Chromatic thresholds for the four colors, nasal meridians.

A further corollary of the change in the ratio of sensitivity to the different colors in passing from the center to the periphery of the retina, is the change in hue of red and green. This change is toward yellow when the observation is made with a preexposure and surrounding field of the brightness of the color, and there is a proper control of all other variable factors. If the observation is not made under these conditions, the change may be still more complicated. The change toward yellow depends upon two facts: (a) The red and green wave lengths of light have the power to arouse not only the sensations of red and green, but also weakly the sensation of yellow; and (b) sensitivity to red and green falls off more rapidly than to yellow in the mid periphery of the retina. In the center of the retina, which is fully sensitive to red and green, the weakly aroused yellow excitation is below the threshold of sensation, i. e., too weak to be sensed in the presence of the strongly aroused red and green sensations. However, in those parts of the periphery of the retina in which the loss of sensitivity to red and green is greater than to yellow, the yellow component of the sensation comes above the threshold, and the red and green stimuli are sensed as yellowish-red and yellowish-green.

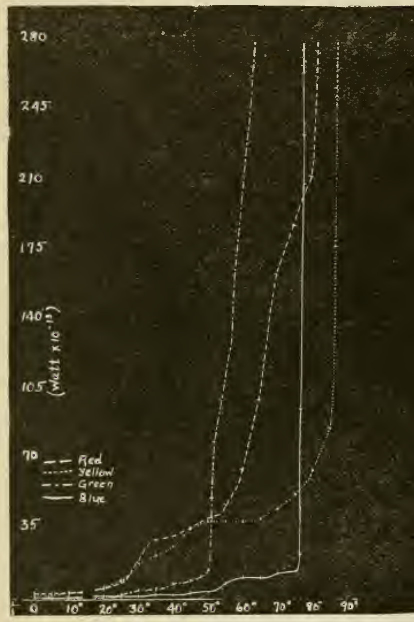

Chart 3. Chromatic thresholds (enlarged scale) for the four colors, temporal meridian.

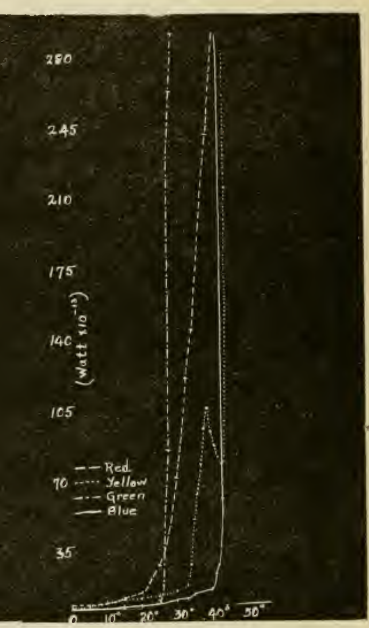

Chart 4. Chromatic thresholds (enlarged scale) for the four colors nasal meridian.

For example, in passing from the center to the periphery of the retina in the temporal meridian, the red stimulus was sensed as red from the center to about 60° by the observer whose threshold results are given in charts 1-4; from 60° to about 86° it was sensed as yellowish-red or orange; from 86° to the limits of sensitivity it was sensed again as red. Corresponding to this it will be noted (charts 1-4) that there is in this meridian a fairly close agreement in sensitivity to red and yellow from the center to about 60° (stimulus sensed as red), at which point there is a relatively sharp decrease in sensitivity to red. That is, from 60° to 86° there is much less sensitivity to red than to yellow (stimulus sensed as yellowish-red or orange). At about 86° there is a sharp decrease in sensitivity to yellow, and from this point on to the limits, a fairly close agreement again in sensitivity to the two colors (stimulus sensed as red). In the nasal meridian, the red stimulus was sensed as red from the center of the retina to about 30°; from there to about 47° as yellowish-red or orange; and from 47° to the limits of sensitivity, as red. Similarly in this meridian, there is a fairly close agreement in sensitivity to red and yellow from the center to about 30°; from 30° to about 47° there is a considerably greater sensitivity to yellow than to red; and from this point on to the limits, greater sensitivity to red than to yellow. In case of green, in the temporal meridian the greater loss in sensitivity to green, as compared with yellow, begins at about 51°; and in the nasal meridian at about 26°. Correspondingly, at these points the green stimulus began to be sensed as yellowish-green and continued to be sensed in this hue until the limits of sensitivity to green were reached, from which point on, for a short distance, it was sensed as unsaturated yellow.

These changes of hue are the normal changes for spectrum or pure red and green in passing from the center to the periphery of the retina when, as we have already stated, there is no achromatic effect of preexposure and surrounding field, that is, when the preexposure and surrounding field are a gray of the same brightness as the color, and when the general illumination of the room is held constant. In a later paper, the changes produced by a preexposure and surrounding field lighter or darker than the color, and by a variable illumination will be given.

In chart 2, nasal meridian, a gap will be noted in the curve for blue not present in the curves for the other colors. In this area is represented a peculiar type of color blindness, small areas or spots which are found, so far as we have been able to discover, in all or most peripheral retinas. In these spots, the blindness is to one color alone. The spot is fully sensitive to all of the other colors. Moreover, it shows no deficiency in the cancelling, after image and contrast reactions of the color in question. That is, in this area the stimulus, altho it is not sensed as color, has just as much power to cancel the complementary color and to arouse the complementary colored after image as it has in the immediately surrounding retina. These spots seem not to be subject to change and apparently are not pathologic.

An examination of a large number of observers shows, that eyes may differ widely with regard to the number and size of these spots, their location and the color affected. A successful search of the peripheral retina for the presence of such spots requires a means of making a rather minute investigation of the retina from the center to the periphery in a number of meridians. A more detailed report of the study of this phenomenon has been reported in an earlier paper.[18] F. Schumann[24] reports a case (his own) in which the whole retina is affected by this type of color blindness. In case of these small areas, also in the Schumann case, the defect which renders the eye blind to the color in question seems to be located posterior to the functional level which is the seat of the cancelling, after image and contrast reactions, else these reactions would be disturbed in some proportion to the disturbance in the power to sense the color in the positive sensation. It would be of interest to know whether the cancelling, after image and contrast reactions are retained also in the relative scotomata of pathologic origin. This point will be made the subject of future study.

CONDITIONS UNDER WHICH THE THRESHOLDS WERE DETERMINED.

(1) The colored lights were taken from the spectrum and special precautions were exercised to secure a high degree of purity. There are two reasons for this in an investigation of the kind here undertaken: (a) The stimuli should be as homogeneous as possible with regard to the visible wave lengths. The presence of alien visible wave lengths affects the results of a determination of chromatic sensitivity in two ways. Thru physiologic inhibitions and interactions it decreases the amount of the color response; and it increases the energy measurement. In both of these ways the value of the threshold is raised by the presence of impurities in the stimulus light. And (b) the stimuli should be free from the infra-red and ultraviolet radiations, which would affect the thermopile used to measure the intensity of light, but not the eye.

The stimuli employed were a narrow band of red in the region of

670$\mu\mu$.; of yellow in the region of 581$\mu\mu$.; of green in the region of 522$\mu\mu$.;and of blue in the region of 468$\mu\mu$. The breadth of the analyzing slit used in isolating these bands was maintained constant at 0.5 mm. The ranges of wave lengths obtained were approximately 660-680$\mu\mu$.; 575-587$\mu\mu$.; 518-526$\mu\mu$.; and 464-474$\mu\mu$. The spectrum was gotten and the different wave lengths were presented to the eye by means of an apparatus[12] already described. In every case the light was examined for impurities at the analyzing slit by means of a small Hilger direct vision spectroscope provided with an illuminated scale. When found, impurities were absorbed by thin gelatins selected so as to cut out as little as possible of the useful light. These gelatins were placed over the analyzing slit and were held in position by short clips fastened to the front surface of the jaws, the edges of which formed the slit.

(2) The determinations of the thresholds were made in energy terms. Measurements were made at two places: at the analyzing slit and at the eye. The method of making the energy measurements by means of a thermopile has been described in previous papers.[25] The values given in charts 1-4 are total amount of light entering the eye.

(3) The field surrounding the stimulus and the preexposure were always maintained as nearly as possible at the same brightness as the stimulus at the threshold value of sensation. These surfaces were made from the Hering standard gray papers. It was found to be necessary to change the brightness of the surrounding field and preexposure frequently for each stimulus, because the brightness value of the color at the chromatic threshold changed quite rapidly from the center toward the periphery of the retina. There were two causes for this change: (a) The intensity of light had to be increased a great deal from center to periphery to give the chromatic threshold from point to point; and (b) the achromatic value of the colors does not remain the same from the center to the periphery of the retina (the Purkinje shift of the peripheral retina). The match of color to gray was made in every case for the point of the retina under investigation.

(4) The illumination of the room was kept at a constant value. Its value on the working surface was 30.49 foot candles. Two features are necessary for this control: (a) A means must be had of detecting small changes of illumination. This may be accomplished by a portable photometer of the Sharp-Millar or Macbeth types furnished with a daylight screen, or of the simpler type described by the writers in a previous paper.[13] And (b) a means must be had also of producing small variations in the illumination of the room, else the changes due to fluctuations in the external light can not be compensated for with the precision and minuteness of control that is needed. This is accomplished in our optics room[23] by two systems of thin white curtains running on spring rollers beneath the skylight. Large changes are produced by a light proof curtain. One of the systems of white curtains and the light proof curtain run lengthwise of the room; the other system of white curtains runs across the room. By means of the white curtains, either small local or small general changes can be produced in the illumination of the room; and by means of the light proof curtain, larger changes may be produced ranging from full illumination to the darkness of a moderately good dark room. The light proof curtain is of a breadth equal to that of the room and runs in a light tight boxing. The white curtains are narrower and are made to overlap at the edges. These latter curtains run on wire guides to prevent wrinkling or sagging. Above these curtains are pivoted two large diffusion sashes of glass, ground on one side completely filling the skylight opening. These sashes diffuse the light in the room, giving an even distribution of illumination and rendering, because of that fact, an even and precise control easier to accomplish.

(5) The results were made independent of the size of the pupil. Breadth of pupil affects the results of

a determination of the sensitivity of the peripheral retina in the following ways: It influences the clearness of imaging, the amount of light entering the eye, and, by limiting the angle at which the beam of light may enter the eye, the degree of excentricity at which an image may be formed on the retina. Independence of change in size of pupil was especially needed in this work, because of the large variations in the intensity of light used. Such control is very easy to accomplish with the means of presenting the light to the eye that is used in our spectroscopic apparatus. All that is needed is to keep the image that falls on the pupil of a constant size and smaller than the pupil thruout its entire range of variations in the given series of experiments. Not only can this variation be determined in preliminary experiments as a guide to the size of image that is needed, but the image itself can be compared with the pupil at each observation.[14]

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THE EFFECT OF INTENSITY OF STIMULUS ON THE SIZE AND SHAPE OF THE COLOR FIELDS AND THEIR ORDER OF RANKING AS TO BREADTH.

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BRYN MAWR, PA.

The influence of illumination on the size and form of the color fields is here shown. The data for the charts given were obtained under illuminations varying from 0.03 to 51 foot candles. Measurement of the illumination of a well lighted room showed that it was equal to 51 foot candles at 1 p. m., and 3 foot candles at 4:15 p. m. on a bright winter day. Such variations of illumination produced changes in the field for red by amounts ranging in different meridians from 11° to 37°; for blue of 13° to 37° and for green 10° to 19°.

In a previous paper[1] the effect of changes in the intensity of the stimulus light on the size and shape of the color fields and their order of ranking as to breadth was discussed, and an explanation was found for these effects in the

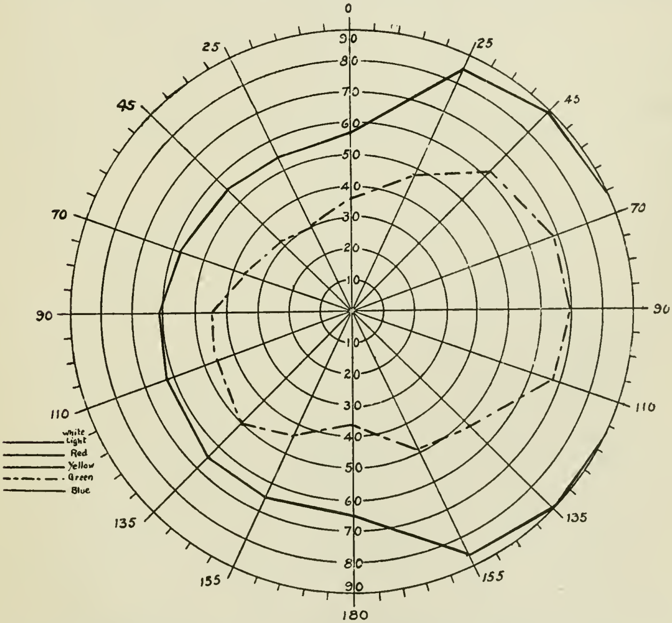

Fig. 1.—The effect of intensity of stimulus on the limits of sensitivity, prismatic spectrum. In this chart are represented the limits of sensitivity for intensity A: red, 9096.639; yellow: 4065.624; green, 1526.388; and blue, 882.025 watt x 10^{-10}.

The above values represent total energy at the stimulus opening in the campimeter and at the eye. The energy density at the stimulus opening (watt per sq. mm.) may be obtained by multiplying the above values by 0.005659; the energy density at the eye, by multiplying them by 0.303.

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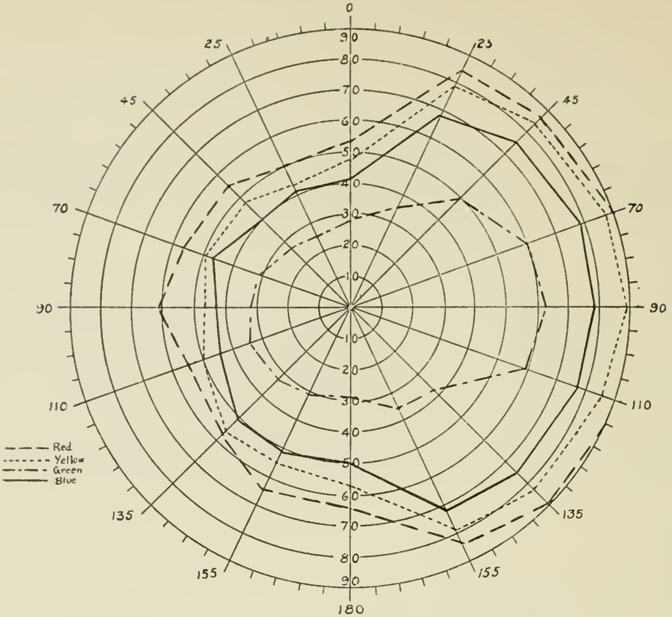


Fig. 2.—In this chart are represented the limits of sensitivity for intensity 1/32 A; red, 284.27; yellow, 127,051; green, 48,825, and blue, 27.563 watt x 10^{-10}.

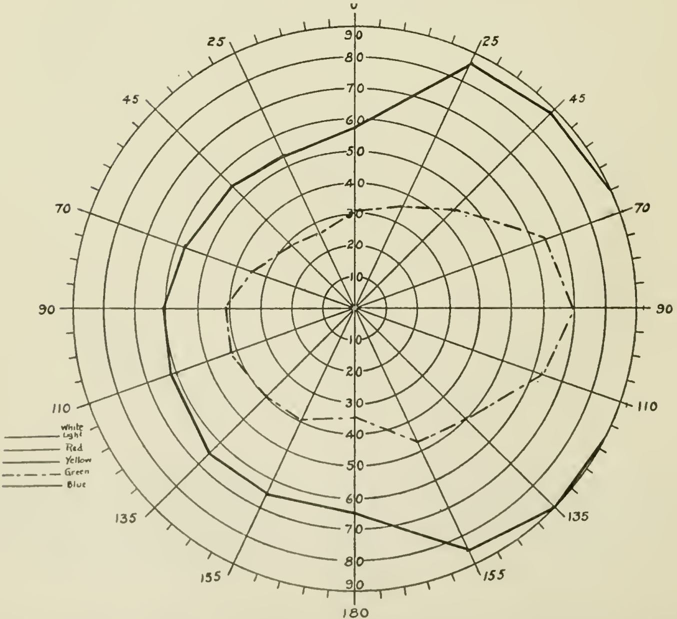


Fig. 3.—In this chart are represented the limits of sensitivity B: red, 891.05; yellow, 882.51; green, 884.946; and blue, 882.025 watt x 10^{-10}.

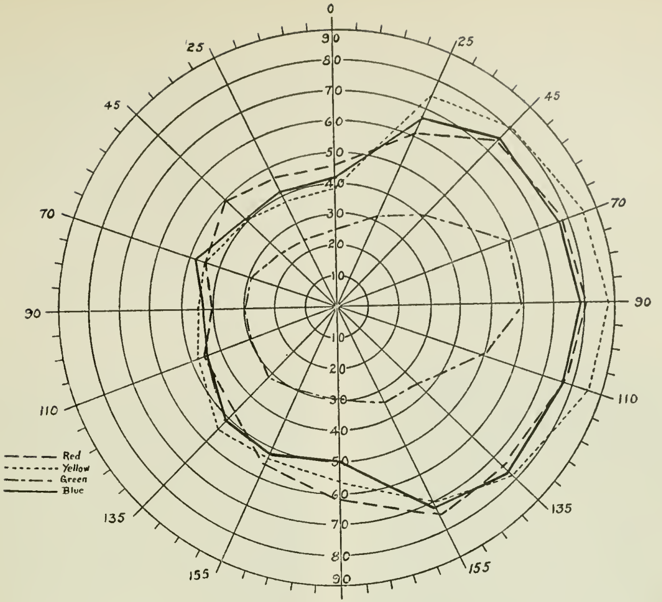


Fig. 4.—In this table are represented the limits of sensitivity for intensity 1/32 B: red, 27.845; yellow, 27,578; green, 27.655, and blue, 27.563 watt x 10^{-10}.

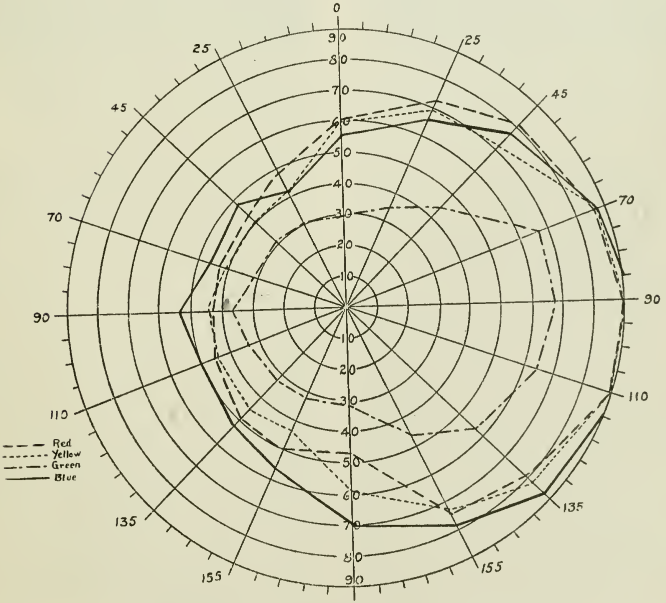


Fig. 5.—The limits of sensitivity to red, yellow, green and blue of the Hering series of pigment papers, intensity of illumination, horizontal component, 130 foot candles.

irregular distribution of color sensitivity over the retina of the normal eye. Four curves were given illustrating this irregularity of distribution, in terms of the amount of light required just to arouse the color response at near lying points from the center to the periphery of the retina. Briefly summarized the situation is as follows:

(1) The sensitivity to a given color falls off towards the periphery at different rates in the different meridians; therefore, a decrease in the intensity of the stimulus light causes the field to contract by different amounts in the different meridians, or to change its shape. (2) At some points (or rather over some regions) in the periphery of the retina, the sensitivity to red is greater than to blue, and at others in the same meridian the reverse of this is true. Because of this fact, a reversal of the order of ranking of the fields as to breadth occurs as the result of a change of the intensity of the stimulus light, a change which is frequently no greater than is produced by the variations in the daylight illumination of a well lighted room during the working hours of a single day.

In the present paper, maps will be given showing the effect of changes in the intensity of the stimulus light on the color fields. Results will be included for two sets of conditions: high intensities, the fields having been taken with a rotary campimeter[2] designed especially for the use of spectrum lights over a wide range of intensities; and medium and low intensities, the fields having been taken with the clinic perimeter[3] described in an earlier paper, designed for the use of pigment stimuli under controlled illumination.

COLOR FIELDS WITH SPECTRUM AND PIGMENT STIMULI AT HIGH INTENSITIES.

In this series of determinations, five intensities of light were used: the prismatic spectrum of a Nernst filament operated by 0.6 ampere of current, intensity A (Fig. 1); the colors of this spectrum reduced to 1/32 of their original intensity, 1/32 A (Fig. 2); an equal energy spectrum in which the colors used were all made equal in physical intensity to the blue (the color of least energy of the series which we have called intensity (A), intensity B (Fig. 3); the colors of this series reduced to 1/32 of their original intensity, intensity 1/32 B (Fig. 4); and the Hering standard pigments: red, yellow, green and blue illuminated by 130 foot candles of light, horizontal component (Fig. 5).

For the spectrum stimuli, narrow bands in the region of 670 μμ., 581 μμ., 522 μμ. and 481 μμ. were used. The breadth of the analyzing slit used to isolate these bands was maintained at 0.5 mm. The ranges of wave length obtained were approximately 680-660 μμ., 587-575 μμ., 526-518 μμ., and 474-468 μμ. The spectrum was gotten and the different wave lengths were presented to the eye by means of the apparatus described in the Journal of Experimental Psychology, 1916, I, pp. 247-284: "A Spectroscopic Apparatus for the Investigation of the Color Sensitivity of the Retina, Central and Peripheral."

In every case the light was examined for impurities at the analyzing slit by means of a small Hilger direct vision spectroscope provided with an illuminated scale. When found, impuritise were absorbed by thin gelatin filters, selected so as to cut out as little of the useful light as was possible. These gelatines were placed over the analyzing slit and were held in position by short clips fastened to the front surface of the jaws, the edges of which formed the slit. The presence of alien visible wave lengths affects the results of any determination of color sensitivity in two ways: (a) Thru physiologic inhibitions and interactions they decrease the amount of the color response. The effects of the presence either of complementary or noncomplementary wave lengths is to exert a canceling or inhibiting action on the chromatic response, the action of the former being, of course, the greater. And (b) they increase the values of the energy or other type of measurement of the amounts of light employed. This has the effect of correlating the sensation aroused with a higher intensity of light than is effective for sensation.

Other precautions exercised to control the influence of variable factors were as follows: (1) The determinations were made with the preexposure and surrounding field of the same brightness as the stimulus color at the limits of sensitivity. (2) The intensity of the general illumination was held constant at 30.5 foot candles horizontal component, for the spectrum colors and 130 foot candles for the pigment papers. The work was done in an optics room designed especially for the control and uniform distribution and diffusion of daylight illumination. (3) The amount of light entering the eye was made independent of variations in the size of the pupil. Such control is very easy to accomplish with the means of presenting the light to the eye used in the apparatus employed. That is, by means of the optical system of this apparatus, the light from the spectroscope was first collimated and then focused on the eye, forming an image of the analyzing slit in the pupil and causing the stimulus opening in the campimeter screen to appear to be uniformly filled with light. All that was needed therefore to maintain the amount of light entering the eye at a constant value was to keep this image always of the same size and smaller than the pupil. The stimulus opening of the campimeter screen formed a visual angle of 3°26′ at the eye. (4) The correctness and constancy of the position of the head was secured by the biting of a mouth board, the position of which for the exact location of the eye at the center of the system had previously been determined by a convenient appendage to the apparatus described in the articles referred to.

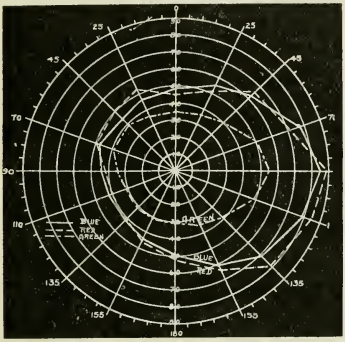


Fig. 6.—Fields taken under 51 foot candles of light, an illumination equal to the daylight falling on the perimeter at the fixation point when facing a window on a bright day, 1 p. m., Jan. 14, 1921.

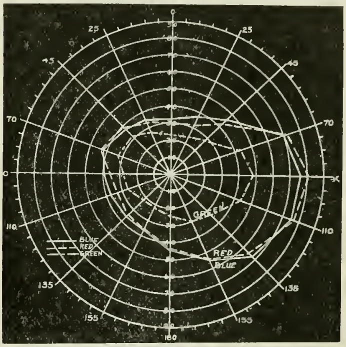


Fig. 7.—Fields taken under 17 foot candles of light, an illumination equal to the daylight at the fixation point, on the same day at 2:30 p. m., perimeter facing window; or at 11 a. m., perimeter parallel to window.

The fields are shown in Figs. 1-5. At intensities A and B (Figs. 1 and 3), it will be noted that the limits for red, yellow and blue coincide with the limits of white light vision. Green could not be made to have so wide an extent. At intensity 1/32 A, the fields in the order from widest to narrowest are red, yellow, blue and green. That is, at intensities of this order of magnitude, with the distribution of energies found in the prismatic spectrum of a Nernst filament, the limits are concentric, with both red and yellow outside the blue. At intensity 1/32 B, the limits for red, yellow and blue interlace or crisscross. This, it will be remembered, is a spectrum in which the four colors had been made equal in energy to the blue of the preceding spectrum, 1/32 A. That is, 1/32 A with its four colors equalized at the intensity of the blue gave interlacing limits for red, yellow and blue, not concentric in the order from widest to narrowest of red, yellow and blue.

The Hering pigment stimuli under the intensity of illumination used, 130 foot candles, horizontal component, also gave interlacing limits for red, yellow and blue, with fields roughly comparable in breadth with those given by the spectrum colors at intensity 1/32 B. A comparison of this result with the results of the next section of the paper shows that the Hering pigment stimuli gave interlacing limits with the same eye under 130, 53, 17 and 7 foot candles of light, horizontal component, altho the limits for blue tended progressively to pass within the limits for red as the illumination was decreased. At 3 foot candles the limits were concentric for all but one point, where they were coincident, with the blue field wider than the red. At 0.03 foot candles they had reversed for the greater part of the field, the limits for blue lying outside of the limits for red.

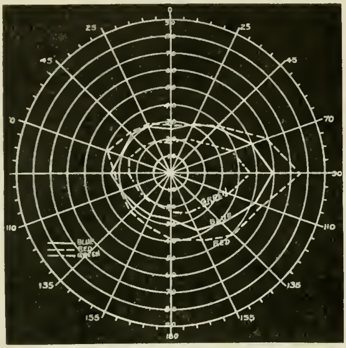


Fig. 8.—Fields taken under 7 foot candles of light, an illumination equal to the daylight at the fixation point, on the same day at 3:45 p. m., perimeter facing window; or at 1:30 p. m., perimeter parallel to window.

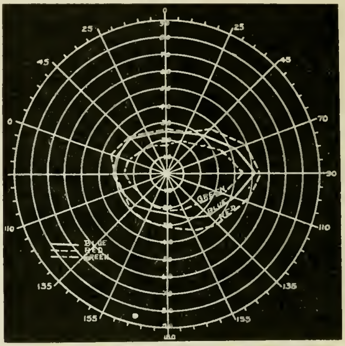


Fig. 9.—Fields taken under 3 foot candles of light, an illumination equal to the daylight at the fixation point, on the same day at 4:15 p. m., perimeter facing window; or at 2:30 p. m., perimeter parallel to window.

THE COLOR FIELDS WITH PIGMENT STIMULI UNDER MEDIUM AND LOW INTENSITIES OF ILLUMINATION.

In this series of determinations, five intensities of light reflected from pigment stimuli were used: the Hering standard pigments under 51, 17, 7, 3 and 0.03 foot candles of light. In order to show how these illuminations compared with the daylight illumination falling on the perimeter arm in an ordinary room, measurements were made of the daylight at the level of the perimeter in a room 30 ft. long with a row of six windows, southern exposure, the lower sills of which were somewhat higher than the perimeter arm. The measurements were made directly in front of one of these windows on a bright day, Jan. 14, 1921. It was found that our highest intensity of illumination, 51 foot candles, was the same as that falling on the perimeter arm at the fixation point with the arm facing the window at 1 P. M.; our second highest illumination, 17 foot candles, was the same as that falling at the fixation point at 2:30 P. M.; the third highest illumination, 7 foot candles, the same as that falling on the fixation point at 3:45 P. M.; and the fourth, 3 foot candles, the same as that falling at the fixation point at 4:15 P. M.

Measurements were made also with the perimeter placed parallel to the window. Our second illumination, 17 foot candles, was the same as that falling at the fixation point at 11 A. M.; our third illumination, 7 foot candles, the same as that at 1:30 P. M.; and our fourth illumination, 3 foot candles, the same as that at 2:30 P. M.

In order to secure the intensities of illumination employed in these experiments, neutral filters of the desired coefficient of transmission were inserted in the aperture of the lamp house provided for the illumination of the perimeter arm. The measurements of the illumination were made as follows: A test plate covered with magnesium oxid deposited from the burning metal was substituted for the stimulus card at the fixation point, and its brightness was measured under the different intensities of light with a Sharp-Miller illuminator. From these brightness measurements, in candles per square foot, the value of the incident light in foot candles was computed. The fields were taken with all of the controls described in our previous paper.[8] They are shown in Figs. 6-11.

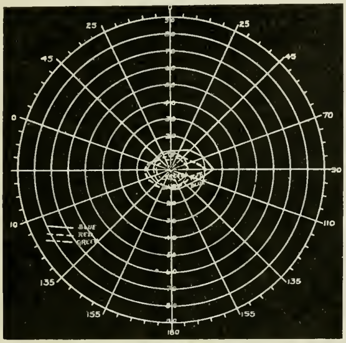
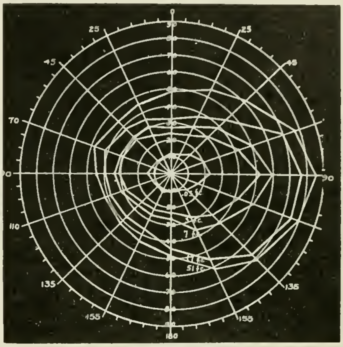
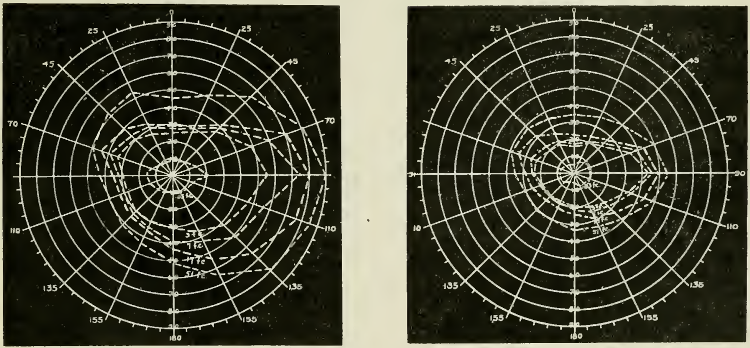


Fig. 10.—Fields taken under 0.03 foot-candles of light.



Fields for blue.



Fields for red.

Fields for green.

Fig. 11.—Showing variations in both the extent and shape of the color fields when taken under 51, 17, 7, 3, and 0.03 foot-candles of light.

The decrease of illumination from 51 to 3 foot candles narrowed the limits for red by amounts ranging in the different meridians from 11 to 37 degrees; for blue, from 13 to 37 degrees; and for green from 10 to 19 degrees, a result, it will be remembered, which was produced by a change of illumination equal to that which occurred from 1:00 to 4:15 P.M. in a well lighted room on a bright winter day. The decrease of illumination from 51 to 0.03 foot candle narrowed the limits for red by amounts ranging in the different meridians from 27 to 72 degrees; for blue, from 29 to 61 degrees; and for green, from 22 to 45 degrees.

The somewhat radical change in the shape of the fields will be noted too for the change of intensities employed; also the change in the relative breadths of the fields. At 51 foot candles of light on the perimeter arm, the boundary of the blue field intersected the boundary of the red field seven times; at 17 foot candles, four times; at 7 foot candles, three times; and at 3 foot candles, it lay entirely within the boundary of the red field, with the exception of at one point, where it was approximately coincident with the limit for red. At 0.03 foot candle, the reverse of this was true for the greater part of the field; that is, the limits for blue lay outside of the limits for red.

It will be seen from the charts in these two sections how little dependence can be placed on breadth or shape of field and order of ranking as to breadth, either in diagnosis or in checking up the advance or recession of a pathologic condition, unless greater precautions are taken for the control of the intensity of the stimulus light, than are possible under the conditions which ordinarily prevail in office and clinic work. Contractions, changes in shape, reversals, spiral fields, etc., may and doubtless do occur, as the result of changes which take place in the daylight illumination of the room in which the fields are taken. Until some means is adopted for general use in the practice of field taking which provides for a constant illumination of the stimulus at every point at which it may be placed in taking the field, not even the first step needed in the systematic application to diagnosis can be taken, namely, an agreement within reasonably satisfactory limits as to what are the normal fields. That the practice of field taking should have been continued so long, in spite of the uncertain and variable results which have been obtained, is, however, a matter of no small significance and encouragement. It is a strong testimonial to the belief in the fundamental importance of field taking in the study of eye diseases.

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EFFECT OF BRIGHTNESS OF PREEXPOSURE AND SURROUNDING FIELD ON BREADTH AND SHAPE OF THE COLOR FIELDS FOR STIMULI OF DIFFERENT SIZES.

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These factors affect the results of field studies made at different times on the same person, or those upon different persons. They make the color stimulus seem lighter or darker, more or less saturated according to the induction by the surrounding field and the after image left by preexposure. Impressions on the periphery of the retina are particularly affected by these factors. The effect is very greatly influenced by the size or visual angle of the stimulus. This work has been done in the Department of Psychology, Bryn Mawr College.

INTRODUCTION.

Two sets of factors lead to variable results in field study: (a) those affecting the results for a given observer, and (b) those tending to give a different result for different observers. The second group includes all of the first and several factors in addition. Without suitable control of the first group the advance or recession of a pathologic condition can not be checked up with the needed degree of precision, and without control of both the first and the second group the satisfactory use of field study in diagnosis presents difficulties.

We have already published considerable data on the effect of the factors of the first group and have described devices and methods for the control of these factors[1]. The factors of the second group will be taken up in later papers. It will be the special purpose of the present paper to show the effect of brightness of preexposure and surrounding field on the size and shape of the color fields, and the differences in effect when the fields are mapped with stimuli of different sizes. A detailed statement of the effect of these two factors on the amount of the chromatic response has been given in earlier papers[2]. A brief explanation and statement of principles will suffice here.

1. When a small colored stimulus surrounded by a field, for example of white or black, is viewed, a sensation is given which consists of the color mixed with black, or white, due to a contrast sensation induced from the surrounding field. The effect of fusing a color with black or white is twofold. (a) There is a quantitative effect, due to the inhibition of the chromatic excitation by the achromatic. In general, in the central retina at medium and high illuminations, white inhibits the colors most, the grays in order from light to dark next, and black the least.

Also the amount of the inhibitive action varies with the different colors, with the part of the retina at which the stimulation takes place, and with the state of brightness adaptation of the retina. The amount of induction depends upon the difference in brightness between the stimulus and the surrounding field; it increases with the distance from the fovea and with decrease in the general illumination; and with a given difference in brightness between the stimulus and the surrounding field, it is greater with a white than with black field,—also the amount of increase of induction, with decrease of illumination and with distance from the fovea, is greater with a white than with a black field.

There is also (b) a qualitative effect. The hue of certain colors is changed by the action of the achromatic excitation. This effect also varies with state of adaptation of the retina and part of the retina stimulated. In central vision the change is greatest when the stimuli are blue and yellow. For example, in case of the light adapted eye, yellow, when mixed with black in central vision gives a greenish yellow, which with the right proportion of components may become an olive green; the blue, when mixed with white or light gray, gives a sensation of reddish blue. In peripheral vision the changes in hue are greater in amount and not always in the same direction as for central vision, and oc-

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cur for other colors besides blue and yellow.

2. When making the color observation in the peripheral retina, the observer is given a short period of preparation before the stimulus is exposed, in which to obtain and hold a steady and accurate fixation. This introduces the factor of preexposure, for during this period of preparation the area which is to be stimulated by color receives a previous stimulation. This previous stimulation, when it differs in brightness from the color, gives a brightness after image, which mixes with the color sensation and both reduces its saturation and modifies its color tone. If the preexposure is lighter than the stimulus color it adds, by after image, a certain amount of black to the succeeding color impression; if darker, it adds a certain amount of white. Since both white and black, as after effect reduce the sensitivity to color, the eye is rendered more sensitive when no after image is given, that is when the preexposure is of the same brightness as the color. The preexposure should, therefore, be a gray of the brightness of the color. No brightness after image will then be added to the succeeding color impression to modify either its saturation or color tone. The only brightness change acting upon it will be due to the slight adaptation to this gray, during the short time of preexposure.

The general principle then is clear. There remains only to explain why in the peripheral retina the short preexposure which takes place while the eye is obtaining a steady fixation has so much effect on the color stimulation immediately following. Two reasons are found for this. (a) The after image reaction of the peripheral retina is extremely quick. While some slight variation is found at different angles of excentricity, in general the peripheral after image seems to reach its maximal intensity with a few seconds of stimulation. This amount of time is usually consumed in obtaining fixation and preparing for the stimulation; hence in each observation there is fused with the color sensation about as strong a brightness after image as can be aroused. For this reason alone it is readily seen why the brightness of the preexposure is of so much greater consequence in the peripheral than in the central retina where the maximal intensity of after image is, roughly speaking, obtained from a stimulation of 40-60 seconds or longer. (b) There is apparently no latent period in case of the peripheral after image. It flashes out at full intensity immediately upon the cessation of the stimulation. Thus there is no possibility of escaping the full effect of the brightness after image on the stimulus color as might happen in the central retina where the latent period obtains, if there were a very short exposure to the stimulus color.

A word might be added also in explanation of the difference in effect for colored stimuli of different sizes. In general a decrease in the size of the stimulus adds to the sensitivity of the perimetric method, or increases the ability to pick up the effect of any factor or condition, normal or pathologic. For example, a given pathologic condition causes a greater shrinkage of the field when mapped with small than with large stimuli. That is, a smaller amount of defect or disturbance in sensitivity can be picked up with a small than a large stimulus. One reason for this is that the use of the smaller stimulus results in a contraction of the field thus bringing the limits into that part of the retina in which sensitivity falls off more gradually, and in which part therefore a given effect on the color response produces a greater amount of contraction of the field. Another reason, as applying to the effect of brightness of the surrounding field, is that there is more intensive achromatic induction over the smaller stimulus, *i.e.*, the amount of induction is influenced by the ratio of area of inducing surface to area of surface over which the induction occurs.

As has already been indicated, the effect of brightness of preexposure and surrounding field falls under the general heading of the inhibitive action of the achromatic excitation on the chromatic. This action takes place however the achromatic excitation is aroused,—by the admixture of white light, by after image, by contrast, etc. It may be strikingly and conveniently demonstrated to large numbers at once, in the following lecture room experiments which we have used for many years. (a) Set up side by side on three mixers discs made up of 180° of color, e.g., blue, and 180° of white; 180° of blue and 180° of gray, of the brightness of the blue; and 180° of blue and 180° of black. When mixed, altho the eye receives the same amount of colored light from each set of discs, the mixture with black seems to have lost but very little color; the mixture with white is a lavender with but little color; and the mixture with gray of the brightness of the color, in this case a very dark gray, is less saturated than the mixture with black. When different grays are used the saturation decreases apparently in graded steps as white is approached. The demonstration can be made on a single color mixer by compounding the color disc with white, black and gray discs of different breadths or radii. When rotated this gives the effect of a surface made up of three concentric zones or rings, one in which the color is mixed with white, one with gray and the third with black. The demonstration may be made roughly quantitative by determining the proportions of color required to give the chromatic threshold in black, white and grays; also by determining the proportions of color and the achromatic series to give equal saturations.

(b) Prepare a preexposure surface, half white and half black, 50x60 cm. Expose the eye 15 to 20 seconds and project the after image on a colored surface, e.g., blue, of the same dimensions. The half of the field preexposed to black will appear a very pale unsaturated lavender while the half preexposed to white will be a dark strongly saturated blue, altho the eye receives the same amount of light from both halves of the field. As the after image dies away the two halves of the field become more and more nearly alike in saturation and color tone. If desired, the preexposure surface may be made of white, black and a series of graded grays, appropriately arranged. When this is done, the graded loss in saturation due to the different brightnesses of the after image may be observed. This demonstration also may be made quantitative by finding the threshold of color after the eye has been preexposed for 15 to 20 seconds to white, black and the grays.

(c) Prepare contrast discs with narrow rings of color and inside and outside surfaces of black, white and a gray of the brightness of the color, respectively. Set up on color mixers side by side and rotate to smooth out all margins. The colors are lightened and darkened respectively by contrast induced by the black and white fields. The effect of these achromatic excitations on the hue and saturations of the colors is similar to that obtained in the former experiments. A more striking effect is produced if a mixed color, e.g., orange, is used. The quantitative features noted above can also be utilized in this demonstration, by employing for the contrast ring in each case, a gray of the brightness of the color and enough of the color to give the threshold of color sensation when acted upon by the white and black inductions.

The effect of induction and after image, it will be remembered, is not nearly so striking in the central as in the peripheral retina. Much more induction, with a given brightness difference between the inducing and the contrast field, for example, is produced in the peripheral retina; and only a short period of preexposure (2-3 seconds) is required to give a strong after image with no latent period.

CONDITIONS UNDER WHICH THE WORK WAS DONE.

The determinations were made on the perimeter described in earlier papers[3]. The illumination was kept constant at 7 foot-candles. Three brightness values were used as preexposure and surrounding field,—a white, a black and a gray of the brightness of the color at or near the point

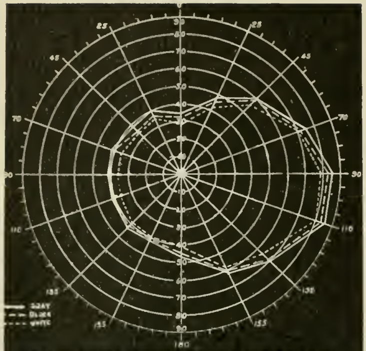

FIG. 1. SHOWING THE EFFECT OF BRIGHTNESS OF PRE-EXPOSURE AND SURROUNDING FIELD ON THE LIMITS OF SENSITIVITY TO RED FOR A STIMULUS SUBTENDING A VISUAL ANGLE OF 2 deg.

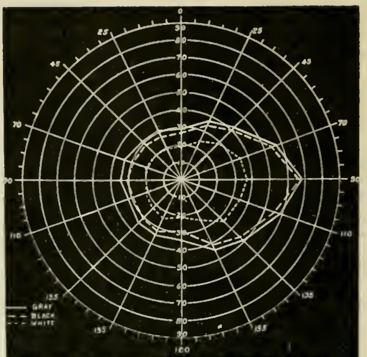

FIG. 2. SHOWING THE EFFECT OF BRIGHTNESS OF PRE-EXPOSURE AND SURROUNDING FIELD ON THE LIMITS OF SENSITIVITY TO RED FOR A STIMULUS SUBTENDING A VISUAL ANGLE OF 1 deg.

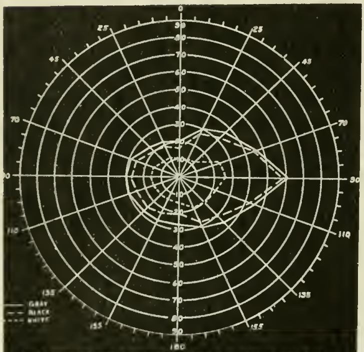

FIG. 3. SHOWING THE EFFECT OF BRIGHTNESS OF PRE-EXPOSURE AND SURROUNDING FIELD ON THE LIMITS OF SENSITIVITY TO RED FOR A STIMULUS SUBTENDING A VISUAL ANGLE OF 0.5 deg.

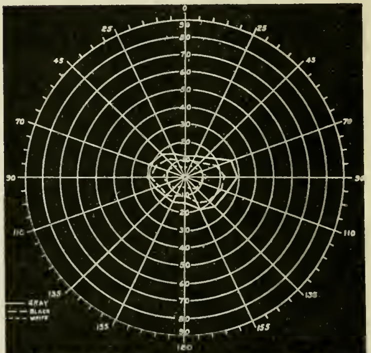

FIG. 4. SHOWING THE EFFECT OF BRIGHTNESS OF PRE-EXPOSURE AND SURROUNDING FIELD ON THE LIMITS OF SENSITIVITY TO RED FOR A STIMULUS SUBTENDING A VISUAL ANGLE OF 0.17 deg.

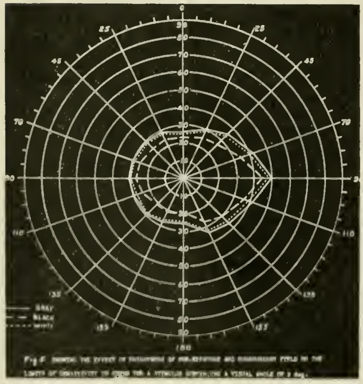

FIG. 5. SHOWING THE EFFECT OF BRIGHTNESS OF PRE-EXPOSURE AND SURROUNDING FIELD ON THE LIMITS OF SENSITIVITY TO GREEN FOR A STIMULUS SUBTENDING A VISUAL ANGLE OF 2 deg.

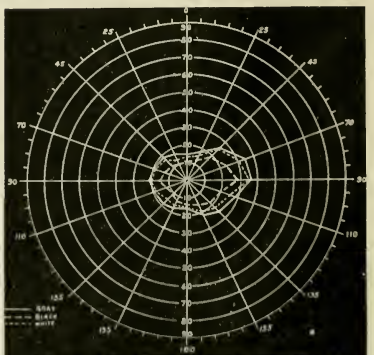

FIG. 6. SHOWING THE EFFECT OF BRIGHTNESS OF PRE-EXPOSURE AND SURROUNDING FIELD ON THE LIMITS OF SENSITIVITY TO GREEN FOR A STIMULUS SUBTENDING A VISUAL ANGLE OF 1 deg.

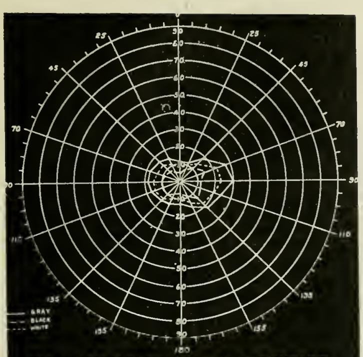

Fig. 7. SHOWING THE EFFECT OF BRIGHTNESS OF PRE-EXPOSURE AND SURROUNDING FIELD ON THE LIMITS OF SENSITIVITY TO GREEN FOR A STIMULUS SUBTENDING A VISUAL ANGLE OF 0.5 deg.

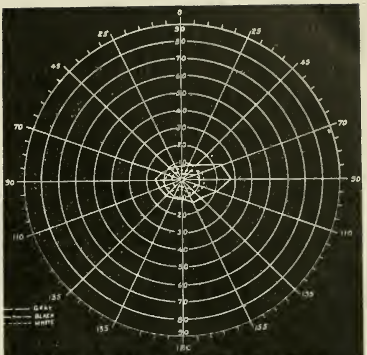

Fig. 8. SHOWING THE EFFECT OF BRIGHTNESS OF PRE-EXPOSURE AND SURROUNDING FIELD ON THE LIMITS OF SENSITIVITY TO GREEN FOR A STIMULUS SUBTENDING A VISUAL ANGLE OF 0.17 deg.

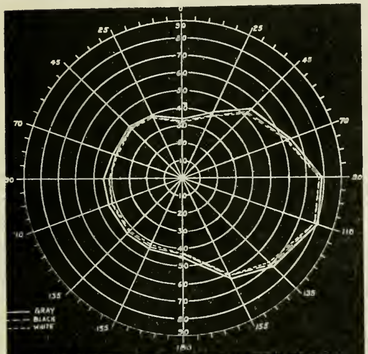

Fig. 9. SHOWING THE EFFECT OF BRIGHTNESS OF PRE-EXPOSURE AND SURROUNDING FIELD ON THE LIMITS OF SENSITIVITY TO BLUE FOR A STIMULUS SUBTENDING A VISUAL ANGLE OF 2 deg.

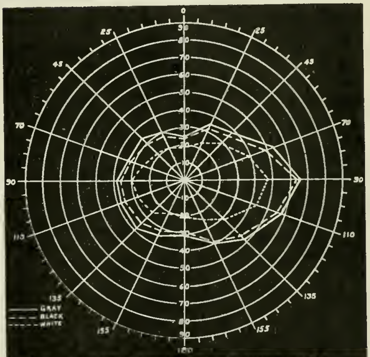

Fig. 10. SHOWING THE EFFECT OF BRIGHTNESS OF PRE-EXPOSURE AND SURROUNDING FIELD ON THE LIMITS OF SENSITIVITY TO BLUE FOR A STIMULUS SUBTENDING A VISUAL ANGLE OF 1 deg.

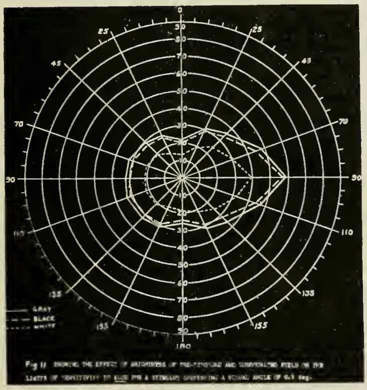

Fig. 11. SHOWING THE EFFECT OF BRIGHTNESS OF PRE-EXPOSURE AND SURROUNDING FIELD ON THE LIMITS OF SENSITIVITY TO BLUE FOR A STIMULUS SUBTENDING A VISUAL ANGLE OF 0.5 deg.

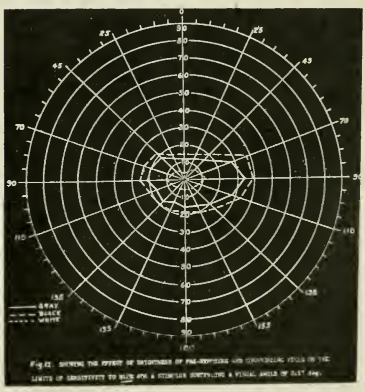

Fig. 12. SHOWING THE EFFECT OF BRIGHTNESS OF PRE-EXPOSURE AND SURROUNDING FIELD ON THE LIMITS OF SENSITIVITY TO BLUE FOR A STIMULUS SUBTENDING A VISUAL ANGLE OF 0.17 deg.

at which the limits of sensitivity occur. The brightness value of the white at the intensity of illumination employed was 0.01367 cp. per sq. in.; of the black, 0.000567 cp. per sq. in. The grays needed to match the colors in brightness were selected from the Hering series of pigment grays in which white is represented by number 1 and black by number 50. Inasmuch as the colors change their brightness when imaged at different degrees of excentricity from the fovea and the different sizes of stimulus carried the limits to different degrees of excentricity in the peripheral field, different grays were required to match the different sizes of stimuli at the limits of sensitivity. In some cases also these grays varied for the different meridians for the same color. The serial numbers of these grays, also their brightness in candle power per square inch under the intensity of illumination used, are given in Table 1. The stimuli used were a red, green and blue of the Heidelberg series of pigment papers. The sizes employed subtended a visual angle at the eye of 2, 1, 0.5 and 0.17 degrees respectively.

RESULTS.

The results obtained are shown in Figs. 1-12 and Tables II-IV.

A precise way of making a quantitative comparison of fields, for the sake of determining numerically the exact effect of any given factor, is to measure the areas of the fields plotted to a standard scale and determine the relations of these areas. The measurements can be made most conveniently by means of a planimeter. We have measured the areas of the fields shown in Figs. 1-12 when plotted to a scale of 1 mm. to 1 degree, and have determined in per cent the amount the field has been changed by each of the

Table I.

Showing the serial numbers and brightnesses in cp. per sq. in.* under 7 f. c. of illumination of the gray pigments (Hering series) which matched the different sizes of stimuli at the limits of sensitivity.

Visual	Red		Green		Blue	
Angle (deg.)	Serial number	Cp. pr. sq. in.	Serial number	Cp. pr. sq. in.	Serial number	Cp. pr. sq. in.
2°	41	.00127	6 3	.00651 .00883	33 31	.00177 .00195
1°	33	.00177	7	.00613	33	.00177
0.5°	41	.00127	7	.00613	29	.00214
0.17°	39	.00161	5	.00682	29	.00214

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* Values specified in candle power per square inch may be converted into milli-lamberts by multiplying by 486.8.

Table II.

Showing the effect of brightness of preexposure and surrounding field on the size of the color field for *red* with stimuli subtending different visual angles. In this table the percentage reduction is computed on the largest field size as base.

Visual Angle (deg.)	Area (sq. cm.)			Amount of Reduction (sq. cm.)			Percentage Reduction		
	Gray	White	Black	Gray	White	Black	Gray	White	Black
2°	99.3	82.5	92.5	....	16.8	5.8	....	16.9	5.8
1°	56.4	22.3	48.8	....	34.1	7.6	....	60.5	13.5
0.5°	37.4	9.2	30.0	....	28.2	7.4	....	75.4	19.8
0.17°	12.6	2.0	8.2	....	10.6	4.4	....	84.2	34.9

Table III.

Showing the effect of brightness of preexposure and surrounding field on the size of the color field for *green* with stimuli subtending different visual angles. In this table the percentage reduction is computed on the largest field size as base.

Visual Angle (deg.)	Area (sq. cm.)			Amount of Reduction (sq. cm.)			Percentage Reduction		
	Gray	White	Black	Gray	White	Black	Gray	White	Black
2°	36.0	33.3	25.0	....	2.7	11.0	....	7.5	30.6
1°	16.8	13.1	8.2	....	3.7	8.6	....	22.0	51.2
0.5°	11.4	7.5	3.2	....	3.9	8.2	....	34.2	71.9
0.17°	6.5	2.5	1.1	....	4.0	5.4	....	61.5	83.1

Table IV.

Showing the effect of brightness of preexposure and surrounding field on the size of the color field for *blue* with stimuli subtending different visual angles. In this table the percentage reduction is computed on the largest field size as base.

Visual Angle (deg.)	Area (sq. cm.)			Amount of Reduction (sq. cm.)			Percentage Reduction		
	Gray	White	Black	Gray	White	Black	Gray	White	Black
2°	94.2	85.6	88.1	....	8.6	6.1	....	9.13	6.5
1°	54.6	27.0	48.4	....	27.6	6.2	....	50.6	11.4
0.5°	40.25	17.9	34.8	....	22.35	5.45	....	55.3	13.5
0.17°	12.5	2.45	17.75	5.25	15.30	....	29.6	86.2	....

preexposures and surrounding fields for each size of stimulus, using the area of the widest field as the base on which to compute the percentage change. In Tables II-IV are given the sizes in sq. cm. of the various fields when plotted on a scale of 1 mm. to 1 degree, the amounts of reduction and the percentage of reduction. These results may be summarized as follows:

(1) The widest angular limits of the color zones were obtained when the preexposure and surrounding field were of the same brightness as the color for all of the colors except blue with the very small 0.17 deg. stimulus. With this stimulus the widest field was obtained with the black preexposure and surrounding field. This result is quite exceptional. It seems to be obtained only when very small stimuli are used. Usually the widest fields are obtained with a preexposure and surrounding field of the brightness of the color. Blue, however, sustains a very close qualitative relation to the gray of the Hering series which matches it in brightness. When very small in size it seems to escape observation entirely on such a background after a certain point of excentricity is reached. For this reason the small amount of induction from the black background seems to be a favorable rather than an unfavorable factor. That is, the influence of this induction on rendering the stimulus more different from its background seems to more than compensate for the small amount of inhibitive action on the chromatic component of the sensation.

(2) With the white preexposure and surrounding field the size of the field for red with stimuli subtending visual angles of 2, 1, 0.5 and 0.17 deg. was reduced 16.9, 60.5, 75.4 and 84.2 per cent respectively; with the black preexposure and surrounding field, 5.8, 13.5, 19.8 and 34.9 per cent. With the white preexposure and surrounding field for green these reductions were respectively 7.5, 22, 34.2 and 61.5 per cent; with the black preexposure and surrounding field they were 30.6, 51.2, 71.9 and 83.1 per cent. With the white preexposure and surrounding field the field for blue with stimuli subtending visual angles of 2, 1 and 0.5 deg., the reductions were 9.1, 50.6 and 55.3; with the black preexposure and surrounding field they were 6.5, 11.4 and 13.5. In the case of blue for the stimulus subtending a visual angle of 0.17 deg., as already stated, the field was widest for the black preexposure and surrounding field. The reduction produced by the gray preexposure and surrounding field was 29.6 per cent; by the white preexposure and surrounding field, 86.2 per cent.

(3) It will be noted that black as a preexposure and surrounding field contracts the limits more for the lightest color, green; and white for the darker colors, red and blue. The explanation for this difference in result is doubtless to be found in terms of the effect of the surrounding field. That is, the greater the brightness difference between the stimulus and its surrounding field the greater will be the induction effect and the greater its inhibitive action on the color.

As a plea for the adoption of better controls in the practice of perimetry it may not be out of place to add in conclusion the following comments. In general two types of method are available for determining the condition of a sense organ, the direct or objective examination and the functional test. Field study of every kind belongs to the latter type of examination. The following are some of the advantages of the functional test over any objective method of making the examination: (1) Perhaps the earliest manifestation of a pathologic condition of any organ is a disturbance of function. It usually comes before a change in structure. (2) In case of the eye the visual field represents a projection of the retina. This projection is magnified in direct ratio of the square of the distance to which it is made. Thru the application of the functional test in the study of the visual field, therefore, a much greater magnification can be secured than by any objective method of examining the nerve fiber layer of the retina or fundus,—that is, a much more minute and searching examination can be made. And (3) as just stated the objective examination shows only the condition of the fundus. The condition of the deeper lying structures can not be revealed by it. The functional test furnishes evidence of the condition of the entire sensorium from retina to brain center. It is obvious that there is great need to develop the possibilities of the functional test as a means of differential study and diagnosis. A sensitive and precise means of early diagnosis is, it scarcely need be pointed out, one of the most important adjuncts of preventive medicine.

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THE BLIND SPOT FOR ACHROMATIC AND CHROMATIC STIMULI.

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The disagreement in the literature as to a color blind zone at the margin of the physiologic blind spot is here discussed. The apparatus and method used to investigate this point are described. The results of observations made are reported in a series of tables, and the differences in size of the blind spot, for white on black, black on white and colors against white, black and gray backgrounds of the brightness of the color, are shown by charts. Reported from the Department of Psychology, Bryn Mawr College.

The blind spot, discovered by Mariotte[1] in 1668, and often called Mariotte's spot, has been the subject of considerable study and discussion during the last two hundred years. Three problems have arisen in connection with this study: (1) the determination of the limits of the blind spot; (2) the space functions of the region immediately surrounding the blind spot; and (3) the filling in of the blind spot. In this paper the first problem alone will be considered.[2]

Various views, five in all, have been held as to the limits of the blind spot. The first view was proposed by Mariotte who held that the entrance of the optic nerve is insensible to light over its whole extent. This view was immediately opposed by Pequet[3] who believed that the entrance of the retinal artery and vein alone were blind. Volkmann[4] and Coccius were the chief supporters of Pequet, while Hannover[5], Weber[6], Donders[7], Listing[8], Fick and DuBois-Reymond[9], Helmholtz[10], and later Wittich[11] and Aubert[12], upheld Mariotte's view, all affirming that the measurements of the blind spot corresponded more closely with the diameter of the entrance of the optic nerve than with the diameter of the retinal artery at its place of entry, as was contended by Volkmann.

Donders and Helmholtz demonstrated directly that the nerve fibers at their entrance were insensible to light. With the aid of an ophthalmoscope, they projected the image of a flame into the eye so that it fell upon the nerve fibers as well as on the blood vessels. They found that no sensation was aroused in either case.

Weber and Hannover advanced the argument that the defective area could not be limited to the blood vessels, as this would give an irregular and branchlike form to the blind spot rather than an area roughly oval in shape, as is demonstrated to be the case.

The third view, that not only is the entrance of the optic nerve blind, but also the area immediately surrounding it, was advanced by Griffin[13] who found that the diameter of the blind spot varied, within limits, inversely as the intensity of the stimulus. This view was supported by Weber[6], Bjerrum[14], Meisling[15], and Groenouw[16], all of whom found the area of absolute blindness to be surrounded by a zone of relative blindness in which large stimuli are visible but smaller ones are not.

The fourth view has been advanced and supported at different times by Johansson[17], Ovio[18], Polimanti[19], Haycroft[20], and Van der Hoeve. They maintain that surrounding the area blind to colorless stimuli is a narrow zone relatively blind to color. Polimanti, for example, found blue and yellow to have narrower limits than red and green, while Haycroft, using as stimuli painted nail heads on a black surrounding field, found the order from widest to narrowest to be green, red, and blue. Van der Hoeve says the absolute scotoma or blind area is surrounded by a zone of one-eighth to one-fourth degree relatively blind to white, and beyond this is a zone of an average breadth of one-half degree, which is relatively blind to color.

The fifth view was advanced by Ramsay and Sutherland[21]. These writers claim, that beyond the zone of relative or transitional amblyopia to white is a zone absolutely blind to color, varying in width for the different colors. This zone is widest in order for green, red, yellow, and blue. Thus, according to Ramsay and Sutherland, the scotoma is larger for colored than for colorless stimuli and is absolute.

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Berens[22], one of the most recent writers on this subject says, "Most authors of today agree that there is a relative scotoma for white and colors surrounding the absolute blind scotoma * * * * Observations of Van der Hoeve and Ramsay and Sutherland are fairly well borne out by the investigations on normal subjects, except that with accurate observers, when using a black screen, daylight illumination, and large colored test objects, the fields for colors, white, and motion all coincide so closely that it is difficult to say that they were not all observed practically at the same time." He states further that the results are erratic and difficult to reproduce, when the determinations are made on a white or light gray field, but that with a black or dark gray screen and constant artificial daylight illumination, his subjects were quite accurate in reproducing their results.

The preceding survey of the literature shows that there is a great deal of disagreement in the results obtained in the work that has been done on the blind spot. Some of this may be due to the individual differences in the eyes investigated, but doubtless the major portion of it may be attributed to the lack of a standard set of conditions under which to work. Until the variable factors, which influence the size and shape of the blind spot, are discovered and controlled there is little chance of doing work on the blind spot with a sufficient degree of precision, or reproducibility, to make it of any considerable value either for practical or scientific purposes. It has been the purpose of the present study to map the blind spots for chromatic and achromatic stimuli, under standard conditions, selected with special reference to the control of the variable factors which influence the results of blind spot determinations. In a later paper the effect of these factors on the size and shape of the blind spot will be shown.

APPARATUS AND METHOD.

The experimental work was done on the Ferree-Rand perimeter. This perimeter was designed for the control of all of the variable factors which effect the determination of the color fields for a given eye. For a detailed description of the instrument the reader is referred to the following publications by Ferree and Rand: "A New Laboratory and Clinic Perimeter," Journ. Exp. Psych., 1922, vol. v. pp 46-67; "An Illuminated Perimeter with Campimeter Features," Transactions of the American Ophthalmological Society, v. XVIII, 1920, pp. 164-172; The American Journal of Ophthalmology, 1922, v. 5, pp. 455-465; Transactions of an International Congress of Ophthalmology, 1922, pp. 388-423.

Among the special features and devices of this perimeter the following may be mentioned: A means of illuminating the perimeter arc, such that every point on the arc in any meridan in which it may be placed receives light of equal intensity and of daylight quality; a means of controlling the brightness of the preexposure and surrounding field; devices and adjustments for the accurate location of the eye at the center of the perimetric system and for securing a steady and precise control of fixation; special fixation controls for eyes suffering from presbyopia, high degrees of hyperopia and myopia, low central acuity, and central scotomata; attachments for studying the blind spot and for refracting the peripheral field; a tangent screen or campimeter attachment, which can be equally illuminated at every point on its surface and with which all of the fixation devices noted above can be used; etc.

The special features of this instrument which are of particular value for blind spot study are: The provisions for the control of intensity, color and evenness of illumination; the devices and adjustments for the accurate location of the eye at the center of the perimetric system and for securing a steady and precise control of fixation; and the special attachments for blind spot work, providing for the control of the brightness of the surrounding field and other variable factors.

One of these attachments consists of a special carrier in which may be inserted as desired the specially prepared paper screens on which the blind spot is to be mapped. These screens are larger than those used for field-taking and extend farther below than above the center of the perimeter arc to accord with the location of the blind spot with reference to the horizontal meridian. These screens may be white, black, grays of the brightness of the color, etc., as the needs of the work may require. On each screen is stamped 24 equally spaced lines or meridians, radiating from the center outwards. These meridians serve as guides for the movement of the stimulus in determining the limits of the blind spot, or when checking up the location of the limit by a second or third determination. After the determination these screens may be removed and filed as a permanent record, from which the outline of the blind spot may be transcribed.

In using this attachment for mapping the blind spot, the perimeter arc is turned into the horizontal meridian and the carrier moved along the arc until its center coincides with the center of the blind spot. The center of the blind spot is located for a given eye by determining the nasal and temporal limits for an achromatic stimulus, white on black, or black on white, and finding the point midway between these limits, the degree of eccentricity of which can be read on the perimeter arc. In centering the carrier the pointer on its back is moved to this degree value on the perimeter arc.

In determining the limit of the blind spot in any meridian the stimulus is passed along that meridian towards the insensitive area until the observer reports its disappearance. Its direction is then reversed until it reappears. The points of disappearance and reappearance should coincide, for an accurate observer. In case of the present study, when they were not found to coincide the average value was taken after several observations, provided that the distance between the points was less than the breadth of the stimulus, 25 min. or 0.4 deg. If the error did not fall within these limits the result was discarded as unreliable. It may be noted in this connection that it was necessary to take the average of the points of disappearance and reappearance in case of only a very few observers. After a little practice the percentage of error of most of the observers was very low indeed.

Frequent rest periods were allowed to guard the eye against fatigue. This is important in blind spot work for color. Some observers fatigue to color so rapidly on the margins of the blind spot that it is advisable to rest the eye for a few seconds between each excursion of the stimulus to or from the blind area. If this is not done the results are erratic and unnecessary changes in hue are obtained. The precaution is not nearly so important when achromatic stimuli are used.

The stimuli employed were small discs 2.5 mm. in diameter, cut by means of a special punch. As already noted these stimuli subtended a visual angle of 25 min. at the eye 33 cm. distant. The chromatic stimuli were obtained from the Heidelberg papers, red, blue, and green; the achromatic stimuli from the Hering white and black papers. For convenience of use these stimuli were mounted at the ends of slender rods, painted to match the screens on which the determinations were made. The perimeter and table on which it stood were painted mid-gray to avoid extremes of brightness preexposure, during the rest periods and the preliminary period of adaptation.

White, black and grays of the brightness of the color, as seen on the edges of the blind spot, were used as screens on which to make determinations. These were taken from the Hering series of standard papers. The gray used for the red and blue stimuli was number 11 of this series, coefficient of reflection 24 per cent; and the gray for the green stimulus was number 6, coefficient of reflection 42 per cent.

The intensity of illumination of the perimeter arc and blind spot screen was kept constant at 7 foot-candles. Constancy of illumination was secured by ammeter and rheostat control of the

TABLE I.

Blind Spots for Achromatic and Chromatic Stimuli: Area in square centimeters.

Stimulus Field	White Black	Black White	Red Gray	Red Black	Red White	Blue Gray	Blue Black	Blue White	Green Gray	Green Black	Green White
Case 1.....	11.2	11.6	13.2	13.8	13.5	12.1	12.6	20.0	11.9	14.6	25.0
Case 2.....	11.2	13.0	16.2	15.5	22.5	14.0	14.1	20.7	14.6	16.2	25.0
Case 3.....	6.0	7.8	10.9	13.3	14.6	12.0	11.0	19.8	9.9	27.3	20.7
Case 4.....	5.7	9.7	16.2	20.2	19.0	13.3	17.6	23.5	12.2	16.3	17.5
Case 5.....	7.1	6.7	7.1	10.5	11.9	10.1	9.9	13.5	8.0	10.5	16.2
Case 6.....	7.2	7.0	7.3	9.9	8.7	8.7	11.3	9.3	8.7	8.4	12.7
Case 7.....	10.0	7.4	15.2	11.4	12.6	14.5	11.6	23.8	10.2	13.1	30.8
Case 8.....	11.6	10.0	11.0	13.0	15.2	11.8	13.0	14.2	14.3	15.8	16.3
Case 9.....	7.2	9.0	12.3	13.5	16.9	13.0	12.4	16.3	11.6	13.0	17.9
Case 10.....	7.3	8.4	9.6	10.4	10.3	8.9	10.2	17.1	11.4	9.3	16.7
Average*....	8.43	9.06	11.90	13.15	14.52	11.84	12.37	17.82	12.22	14.45	19.56
Median......	7.85	8.70	11.65	13.15	14.05	12.05	12.00	18.45	11.75	13.85	17.70

*By average in this and the following tables is meant the arithmetic mean, obtained by dividing the sum of the values by the number of cases. Because of the small number of cases the median value is also given.

TABLE II.

Blind Spots for Achromatic and Chromatic Stimuli: A Comparison of the Size, for Color and for White on Black.

Field	Average Area in sq. cm. Gray	Average Area in sq. cm. Black	Average Area in sq. cm. White	Per cent larger for color than for white on black Gray	Per cent larger for color than for white on black Black	Per cent larger for color than for white on black White
White stimulus	.....	8.43	.....	....	....	....
Red stimulus	11.90	13.15	14.52	41.1	56.1	72.1
Blue stimulus	11.84	12.37	17.82	40.4	46.7	111.3
Green stimulus	12.28	14.45	19.56	45.6	71.4	132.0

TABLE III.

Blind Spots for Achromatic and Chromatic Stimuli: Average Diameter in Horizontal and Vertical Meridians.

Meridian Field	Gray Cm.	Gray Degrees	Black Cm.	Black Degrees	White Cm.	White Degrees
Horizontal						
White Stimulus	....	....	2.58	4° 28′ 36″	....	....
Black Stimulus	....	....	....	....	2.58	4° 28′ 36″
Red Stimulus	2.91	5° 2′ 36″	3.27	5° 40′ 18°	3.48	6° 2′ 38°
Blue Stimulus	2.81	4° 51′ 30″	3.19	5° 32′ 14″	3.63	6° 18′
Green Stimulus	3.21	5° 34′ 14″	3.43	5° 57′ 8″	4.12	7° 8′ 50″
Vertical						
White Stimulus	....	....	3.89	6° 45′ 36″	....	....
Black Stimulus	....	....	....	....	4.16	7° 14′ 52″
Red Stimulus	4.80	8° 25′ 34″	5.26	9° 6′ 38″	5.26	9° 6′ 38″
Blue Stimulus	4.76	8° 4′ 48″	5.05	8° 44′ 46″	5.50	9° 31′ 34″
Green Stimulus	4.78	8° 16′ 50″	5.37	9° 18′ 22″	6.07	10° 30′ 28″

current operating the lamp used to illuminate the arc of the perimeter. At the beginning of each working period the sensitivity of the eye of the observer was standardized by a twenty minute period of adaptation to the illumination used.

It was impossible in most instances to obtain at a single sitting a complete set of maps between which comparisons were wanted. To guard against comparison being made between results obtained with the eye in a different state of sensitivity the work done at a previous period was always adaquately rechecked, the criterion being that the results obtained at different periods must fall within the same limits of error as those obtained at a single sitting.

RESULTS.

A detailed statement of results is contained in Tables I-III and a graphic

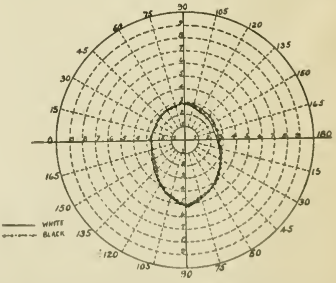

Fig. 1.—Blind spot for a white stimulus on a black field and a black stimulus on a white field (10 observers).

representation in the accompanying maps, Figs. 1-5.

The areas of the blind spots for the different stimuli and conditions employed are given in Table I. These areas were measured by means of a planimeter. They represent the size of the blind spot at a distance of 33 cm. The advantages of measuring the area for comparative purposes is obvious. Only a rough knowledge of comparative sizes can be had from the inspection of the plotted graph or map of this area.

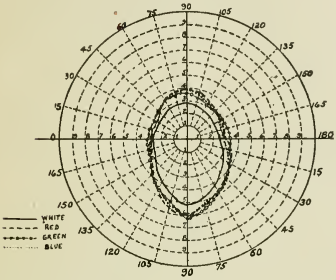

Fig. 2.—Blind spot for red, green and blue stimuli, on gray of the brightness of the color; and for a white stimulus on a black field (10 observers).

This statement applies to the treatment of the results for all types of field study. If a comparison is to be made, with the minuteness and precision needed both for laboratory and diagnostic purposes, a single value or index must be had; which can be taken as fairly representative of the retinal areas under investigation. In case of the blind spot no more accurate and convenient index of the actual extent of the insensitive area can be found, perhaps, than the area of the plotted graph, provided that the limits of sensitivity have been determined and plotted in a sufficient number of meridians. The measurement of this area by means of a planimeter is extremely quick and simple.

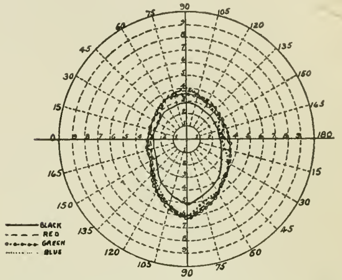

Fig. 3.—Blind spot for red, green and blue stimuli on gray, of the brightness of the color; and for a black stimulus on a white field (10 observers).

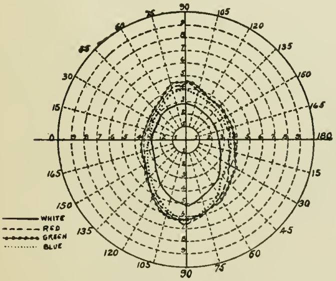

Fig. 4.—Blind spot for red, green, blue and white stimuli on a black field (10 observers).

In Table II is shown the difference in size of the blind spots for the different stimuli and conditions employed. This difference is expressed both in square centimeters and per cent. In computing the values shown in the table the area of the blind spot for white on black was used as the base. This relation of stimulus and background was chosen because of the frequency of its use in clinical work.

The results contained in these tables may be summarized as follows:

(1) The blind spot for achromatic stimuli averages 7.6 per cent larger on

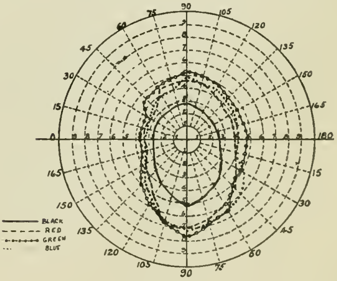

Fig. 5.—Blind spot for red, green, blue and black stimuli on a white field (10 observers).

a white than on a black field. That is, a black stimulus on a white field gave a slightly larger blind spot than a white stimulus on a black field. This difference is in the direction that might be expected. That is, the influence of the irradiation of the white excitation on the retina would tend to increase the area stimulated in case of the white stimulus on the black field, and to decrease it in case of the black stimulus on the white field. Probably because of this, too, a white stimulus on a black field always appears larger than a black stimulus on a white field.

(2) The blind spots for the chromatic stimuli were all much larger than for the achromatic stimuli. The difference is so great as to leave no doubt as to the conclusion that should be drawn. On the gray of the brightness of the color they were 40-45 per cent larger than those for the achromatic stimuli; on the black field, 47-71 per cent larger; and on the white field, 72-132 per cent larger.

(3) Not only the size but the order of ranking as to size varied with the surrounding field. From largest to smallest the order for the white field was green, blue, and red; for the gray of the brightness of the color and the black field the order was green, red, and blue.

In Table III is given the average extent of the blind spot in the horizontal and vertical meridians. These dimensions are given both in centimeters and in visual angle subtended at the eye. The average distance of the center of the blind spot from the center of the field of vision for the achromatic and chromatic stimulus was 16.5°, the range being from 14.5-17.5 degrees.

In a series of papers to be published later, not only the factors affecting the results of blind spot determinations will be discussed, but a diagnostic scale will be prepared for use in clinic work.

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STUDIES IN PERIMETRY. I. PRELIMINARY WORK ON A DIAGNOSTIC SCALE FOR THE FORM FIELD.

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The boundaries of the form field for a white stimulus subtending an angle of 1 degree have been tested in two hundred cases. The areas included within these boundaries have been represented by two methods and the results shown in the accompanying charts. The work has been done in the Graduate School of Medicine of the University of Pennsylvania and the Wills Eye Hospital.

During the past several years papers have been published by two of the present writers describing the apparatus and controls which are required for accuracy and precision in perimetry[1]. The work reported in these studies, however, constitutes only a part of the program which is needed to make perimetry serve a widely useful purpose. A means has yet to be provided for adapting the type of perimetry described to the work of the office and clinic and other fields of application. The present paper is the first of a series designed to carry out this purpose. The studies in this series have been made under the auspices of the Laboratory of Physiological Optics of the Graduate School of Medicine of the University of Pennsylvania.

The determination of the form field has two important clinic uses—a study of the advance and recession of a given pathologic condition, and diagnosis. Both of these uses demand a high precision of working, and a careful control of the variable factors which may influence the result. This precision has been attained within a very small limit of error, insofar as the reproduction of the results for a given individual is concerned. The study of an individual case, therefore, can be made with a degree of accuracy comparable with the most highly developed types of laboratory testing. In diagnosis, however, we have to deal not only with the factors which may cause a variation in result from time to time in an individual, but also with those which differ from individual to individual. These latter factors are being studied at the present time, but the work is not yet completed. Some of these factors may be amenable to control; the greater number, however, in all probability can not be controlled by any procedure which would be feasible for practical work. Two of them at least must always remain outstanding: the normal variation in the sensitivity of

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the retina and in the distribution of sensitivity over the retina.

A highly necessary first step therefore towards the successful use of either the form or color fields for diagnosis is the determination of the range of variation which may be expected for non-pathologic cases. This determination of a norm for the nonpathologic cases and the normal range of variation from an average or median result, is obviously even more necessary for the successful practice of perimetry in its applications to diagnosis and other practical work than the analogous determinations for acuity. In neither case have determinations been made with regard to both of the features indicated above, nor with regard to either with an adequate standardization of factors. In these respects the work in perimetry in particular has been greatly neglected. To make such determinations effective for the practice of perimetry, the following are some of the conditions that must be fulfilled.

(1) They must be made under a prescribed set of conditions which can be widely reproduced. Until the necessity of this constancy of conditions is thoroly understood any plan for calibrating a scale for diagnostic purposes must fail. The wide differences in result which are obtained when care is not taken to control the conditions under which the fields are determined, have been shown in previous papers. An obvious requirement for the validity of application of any scheme of calibration is that the scale which is determined shall be applied only to results obtained under the same conditions as those for which the scale was made.

(2) The results must be treated in such a way as to show the range and distribution of cases as well as the average case. Previous writers on this subject seem to have been content to give the breadth of field in the principal meridians in the average case, or at most only a small range of variation on either side. The knowledge of what is an average field obviously contributes but little to the diagnosis of the cases for which the help of perimetry is most needed. If a pathologic condition is to be diagnosed in its incipiency, the borderline between the normal and the pathologic must be located within reasonably narrow limits. For example, a given field may be much smaller than the average and still fall within the range of normal variation. An adequate scheme of calibration of perimetry for diagnosis should consist therefore of a scale made up of two plots, similar in principle to the well known frequency curve, one for pathologic, the other for nonpathologic cases. In each of these plots the cases should be grouped with reference to size of field along the same coordinate. Such a scale provides a means of placing any new case in the class or group to which it belongs rated with regard to size of field. In obtaining the data for the nonpathologic plot the cases should be sampled broadly to include as many as possible of the outstanding variables. The present determinations which represent only the beginning of the work, have been made to include two of the most important of these variables, namely, age and condition of refraction. The data and range of conditions covered will be increased as opportunity offers.* The data for pathologic cases will not be dealt with at all in this paper.

(3) If extent as well as shape of field is to be used as a diagnostic feature, some accurate means of comparing extents must be had. The means employed at present seem to be a comparison of width of field in the different meridians or an inspection of the plotted fields. Neither of these methods is convenient and in many cases they lead to no definite conclusion. Some fields may be broader in certain meridians and narrower in others than another field or any field or range of fields accepted as standard. The need of a single value or index which will fairly represent the extent of the field

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*It is obvious that the scale presented in this paper may be filled out by each physician from the patients which he examines in his own practice. With 200 cases as a nucleus a scale can soon be formed which will serve a very useful purpose in diagnosis.

is obvious. One solution of this problem is to plot the field to a standard scale and to measure its area with a planimeter. This would be the customary scientific procedure. It would necessitate however that the fields always be plotted to a standard scale or the results be corrected to that scale, and would require, besides, the use of an instrument which may not always be included in the equipment of the office and clinic. For these reasons it has been deemed advisable to find an alternative plan of treating the results which can be used when desired as a substitute for planimetry. A number of methods have been tried and the results checked against those obtained with the planimeter to see which gave the closest agreement. Fortunately a very simple method was found which gives a high correlation with the results obtained with the planimeter. In this method the grouping was based on an average value computed by adding together the distance of the limit in degrees from the center of the field in the several meridians as read from the arc of the perimeter and dividing this sum by the number of meridians in which the determinations were made. This result may be called the average breadth of the field. With regard to this comparison it is only fair to state, however, that the rankings given to the fields by the two methods were not always the same. In such a case it is not easy to decide which method should be used nor, quite aside from considerations of convenience and serviceability, is it easy to say which more correctly represents the distribution of sensitivity over the retina, when the limits are determined only in a comparatively small number of meridians. Obviously either method might be adopted for the purpose of determining norms and of making comparisons with these norms for diagnostic purposes. Results for both methods have been included in this paper.

Conditions Under Which the Fields Were Taken. The experimental work was done on the Ferree-Rand perimeter. This perimeter was designed for the control of all the variable factors which affect the determination of the form and color fields for a given eye. Among the special features and devices of this perimeter, the following may be reviewed here: A means of illuminating the perimeter arc such that every point on the arc in any meridian in which it may be placed receives light of equal intensity and of daylight quality; a means of controlling the brightness of the preexposure and the surrounding field; devices and adjustments for the accurate location of the eye at the center of the perimetric system and for securing a steady and precise control of fixation; special fixation controls for eyes suffering from presbyopia, high degrees of hyperopia, myopia, low central acuity and central scotomata; attachments for studying the blind spot and for refracting the peripheral field; a tangent screen or campimeter attachment, subtending a visual angle of 70 deg., which can be equally illuminated at every point on its surface and with which all of the fixation devices noted above can be used; etc. With such an instrument all of the external conditions of the test can be held constant and be reproduced at will.

The fields were determined with a white stimulus on a black background. The angle subtended at the eye by this stimulus was 1 deg. Its illumination at every point in the field was kept constant at 7 foot-candles. The cases examined included private patients, nurses, assistants on the hospital staff, and a large number of clinic patients. In every instance the refractive condition of the eye was determined and an ophthalmoscopic examination was made. No case showing a pathologic condition, however slight, was included in the series. Ample rest periods were allowed between observations and care was exercised that no field should be taken when the observer was suffering from general fatigue or was otherwise unfit for accurate work. All determinations were carefully checked but the observer was not given extensive preliminary training. It was not the purpose of the writers to make examinations for the determination of norms under conditions differing in this respect from those which obtain in ordinary ophthalmologic work. The results obtained represent therefore a fair sample of the fields that may be expected in an average group of untrained observers who show no pathology.

RESULTS. Fields were determined in 8 meridians (0, 45, 90, 135, 180, 225,

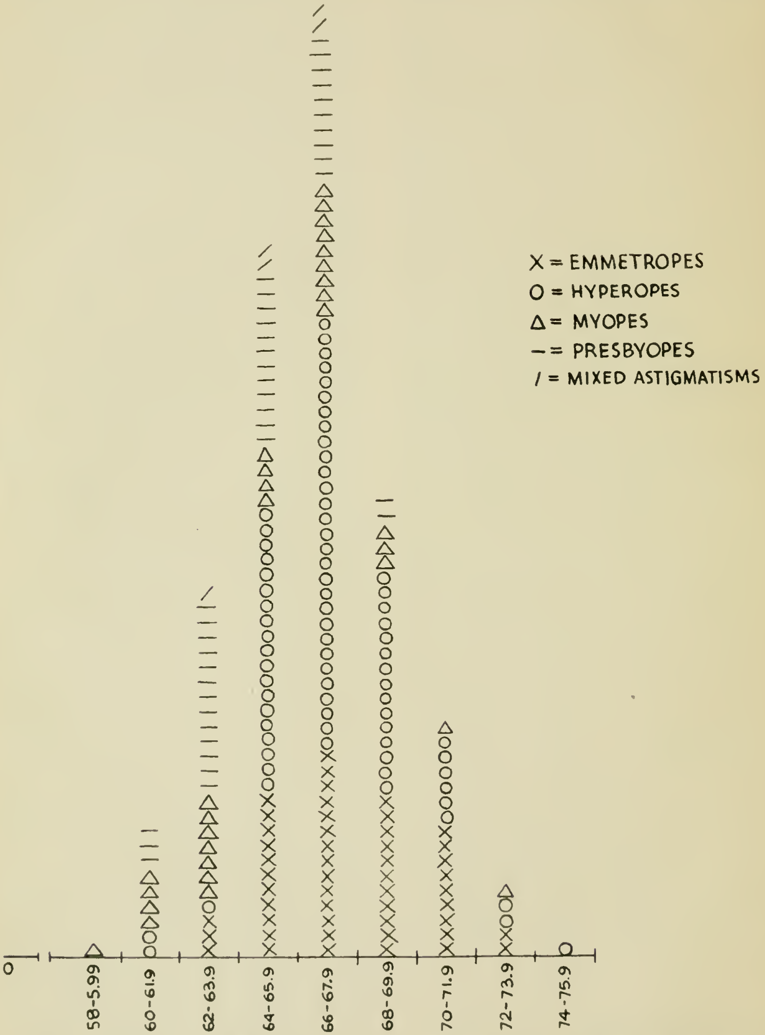

Fig. 1. Showing the distribution of 200 nonpathologic cases. These observers were selected to include cases of emmetropia, hyperopia, myopia, presbyopia and astigmatism. The distribution is based on the average breadth of field in the eight principal meridians. Breadth of field is plotted on the horizontal coordinate and number of cases on the vertical coordinate.

270, and 315 deg.) for 200 eyes. The eyes examined included 75 cases of hyperopia and hyperopic astigmatism, 30 cases of myopia and myopic astigmatism, 40 cases of presbyopia, 5 cases of mixed astigmatism, and 50 cases showing no error of refraction or an error no greater than 1 diopter of hyperopia or 0.25 diopter of hyperopic astigmatism. This latter group contained no cases of myopia or myopic astigmatism. For convenience of treatment it will be referred to as emmetropic.

A graphic representation of the results is given in Figs. 1 and 2. In Fig. 1 the cases are rated on the basis of the average breadth of field in the 8 meridians, expressed in degrees. The total range of average breadth of meridian for the 200 cases was from 58 to 76 deg. For the purpose of grading and representation in the plot the cases were separated into 9 groups, each group covering a range of 2 deg. The number of cases falling in each group is shown on the vertical coordinate. The cases are designated with regard to condition of refraction according to a key shown in the chart.

The results may be summarized as follows:

(1) In general the emmetropes and hyperopes have the wider fields, the myopes, the narrower fields.

(2) Ranked from narrowest to widest the percentage of cases falling in each group is as follows: 0.5, 4.5, 12.5, 24, 32, 15.5, 8, 2.5 and 0.5.

(3) The myopes constitute all of the first group, 44.4 per cent of the second group, 28 per cent of the third group, 8.4 per cent of fourth group, 14.5 per cent of the fifth group, 9.7 per cent of the sixth group, 6.2 per cent of the seventh group, 20 per cent of the eighth group, and none of the ninth group. The presbyopes form no part of the first, seventh, eighth and ninth groups; they form 33.3 per cent of the second group, 52 per cent of the third group, 25 per cent of the fourth group, 14.5 per cent of the fifth group, and 6.5 per cent of the sixth group. Emmetropes are not found in the first, second and ninth groups; they form 12 per cent of the third group, 23 per cent of the fourth group, 22.6 per cent of the fifth group, 35.5 per cent of the sixth group, 56.2 per cent of the seventh group, and 40 per cent of the eighth group. No hyperopes are found in the first group; they form 22.2 per cent of the second group, 4 per cent of the third group, 39.6 per cent of the fourth group, 46.8 per cent of the fifth group, 48.4 per cent of the sixth group, 37.5 per cent of the eighth group, and all of the ninth group.

(4) The distribution obtained, it is interesting to note, is of the type frequently found when a large number of measurements is made of some physiologic or psychologic characteristic. That is, the bulk of the cases cluster around a median value, fewer and fewer occurring as this value is receded from. Whether or not the frequency distribution of field size in nonpathologic cases will be found to fit the normal or Gaussian curve as many other physiologic traits have been found to do, can not be determined until a much larger number of cases has been investigated. The approximation is perhaps as close as can be expected with 200 cases.

Our strongest interest in these results is, of course, their diagnostic serviceability. In discussing diagnostic possibilities the fact must be recognized that in this as in most physiologic studies it will be difficult to draw a sharp line between pathologic and nonpathologic cases. A certain amount of overlapping is to be expected. There will in all probability be a borderline group whose status is doubtful. Indeed one of the chief incentives for refining a test for diagnostic purposes is the desire to reduce the number of cases which must be defined as borderline. Altho 200 is a small number of cases from which to generalize or attempt to form a diagnostic scale, there are a few conclusions which may be drawn from the results obtained with a fair degree of confidence. An examination of Fig. 1 shows for example that there is only one case whose average breadth of field is less than 60 deg. It may be safely concluded, therefore, that any field which has an average breadth of less than 60 deg. must be regarded as suspicious. It will be noted also that there are only 6 cases of emmetropia and hyperopia out of a total of 125 for which the average breadth of field falls below 64 deg. This would seem to justify the conclusion that emmetropes or hyperopes with an average breadth of field less than 64 deg. should be classed as doubtful. Probably we can

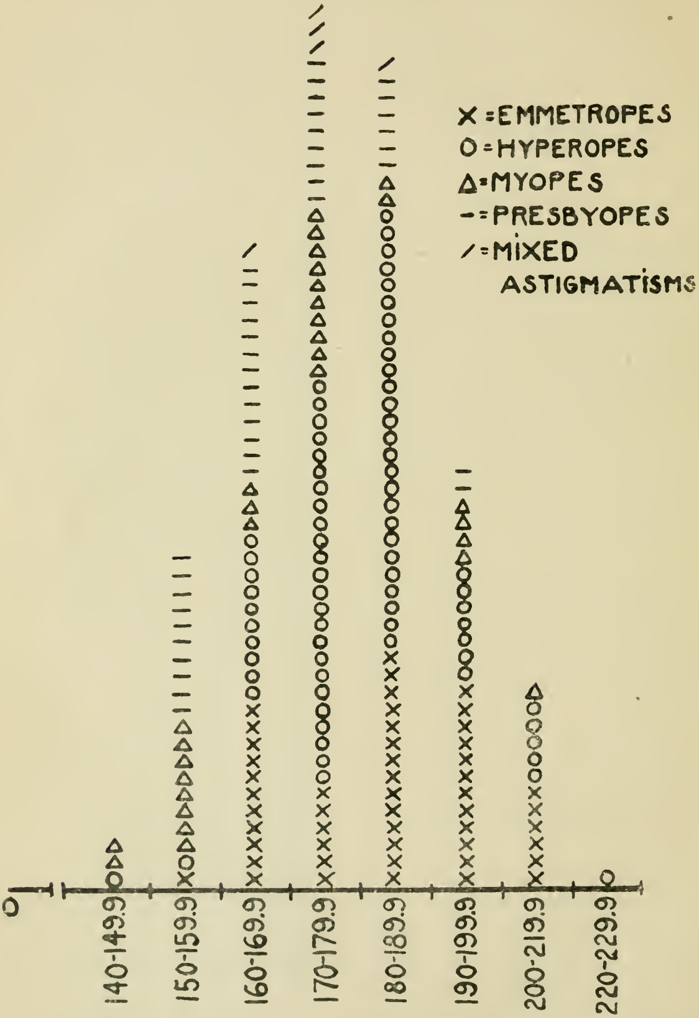

Fig. 2. Showing the distribution of 200 nonpathologic cases. These observers were selected to include cases of emmetropia, hyperopia, myopia, presbyopia and astigmatism. The distinction is based on area of field as measured with a planimeter from maps drawn to a scale of one degree to 1.2 mm. Area of field in square cm. is plotted on the horizontal coordinate and a number of cases on the vertical coordinate.

add too that a myope or presbyope with an average breadth of field less than 62 deg. should be classed as doubtful. The differentiation here, however, is not so clean cut and incisive as in the other cases. In later papers, not only will the data given here for the nonpathologic cases be increased, but comparisons will be made with a large group of pathologic cases in order to give a better understanding with regard to what extent overlapping may be expected. In this connection it should be remembered that we are dealing here only with the more difficult and discouraging aspects of diagnosis by means of the form field, namely extent of field. Changes in the shape of the field are in general much less difficult to evaluate, partly because of the kind of change which is apt to take place as the result of a pathologic condition, and partly because there is a smaller normal variation in shape as compared with size.

In Fig. 2 the results are shown in terms of area of field as measured with the planimeter. The maps measured were drawn to a scale of 1 deg. to 1.2 mm. The total range of area in sq. cm. for the 200 cases was from 140 to 230. In this figure it was deemed advisable to arrange the cases into 8 groups instead of 9, each group covering a range of 10 sq. cm. The number of groups obtained depends of course upon the range selected to form a group. As before, the number of cases in each group is represented on the vertical coordinate and the range of the group on the horizontal coordinate. The condition of refraction of the cases is designated according to the key given in the chart.

In Fig. 3 fields have been plotted to show graphically the more important facts noted above. In this map are given the largest field found, the smallest field, the average field for the 200 cases, and the widest field of each of the two groups which we have called borderline or suspicious. Of these latter two, X represents the widest of the fields whose average breadth falls below 62 deg. Any field smaller than this we have called suspicious for myopes or presbyopes. Field Y represents the widest for the 6 cases of emmetropia and hyperopia whose average breadth was less than 64 deg. Fields for emmetropes or hyperopes smaller than this we would regard as suspicious. An inspection of this map should give a good idea within what limits a field should fall to be within the normal range of variation.

It may be of interest to add here for comparison some data on form fields taken in the Bryn Mawr College laboratory.* With regard to these data the following points may be noted:

(1) The 15 observers used were all under 24 years of age, showed no errors of refraction when examined without a cycloplegic, and had an acuity of 6/6 or better under 5 foot-candles of illumination. Sixteen of the cases in the clinic group showed no errors of refraction without a cycloplegic and had an acuity of 6/6 or better. Their ages ranged from 13 to 29.

(2) The fields were determined in 16 meridians instead of 8 and the observers were given enough practice to secure in each case a close reproducibility of result. The same stimulus and external controls were used as in the preceding work. The method was in general the same with the exception that the greater care and precautions possible in laboratory work were used. It is encouraging and significant to note that such a close agreement can be obtained in a clinic and a laboratory, with a different number and class of observers, different experimenters and for 16 meridians instead of 8, when the work is done with the controls we have selected as standard. Unfortunately, however, this close agreement between clinic and laboratory results has not been found for the color fields. A different standard of work is

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*These fields were taken by F. Selligman and R. Beardsley, students in Bryn Mawr College. The cases for the clinic group were obtained from the Wills Eye Hospital as well as from the clinics of the Graduate School of Medicine. We take pleasure in acknowledging our indebtedness to the chiefs of these clinics who permitted us to use their patients as observers, also to their assistants and the residents of the hospital for help in procuring suitable cases.

required to give a high precision of result in the determination of the color fields than is required in the determination of the form field.

The average breadth of field in the 16 meridians for the 15 observers used in the laboratory determinations was 67.52 degrees; the average in the clinic determinations was 66.38 degrees. The average for the emmetropes and hyperopes of the clinic group was 67.30 degrees; for the myopes and presbyopes, 64.94 degrees; and for the emmetropes alone, 67.38 degrees. The range for the 15 observers was from 62.25 to 72.60 degrees; for the 200 observers, it was 58 to 76 degrees. The range for the clinic group was 72 per cent greater than for the laboratory group. The average, the widest and the narrowest fields for the laboratory group are given in Fig. 4.

SUMMARY.

In former studies by two of the present writers the factors which cause variability in the form and color fields for a given eye were determined and methods and apparatus were devised for their control. This has rendered the use of perimetry for the advance and recession of a pathologic condition comparatively simple and easy. The use of perimetry in diagnosis, the other important application to clinic work, could be made equally easy if the same degree of control could be exercised over the factors which cause

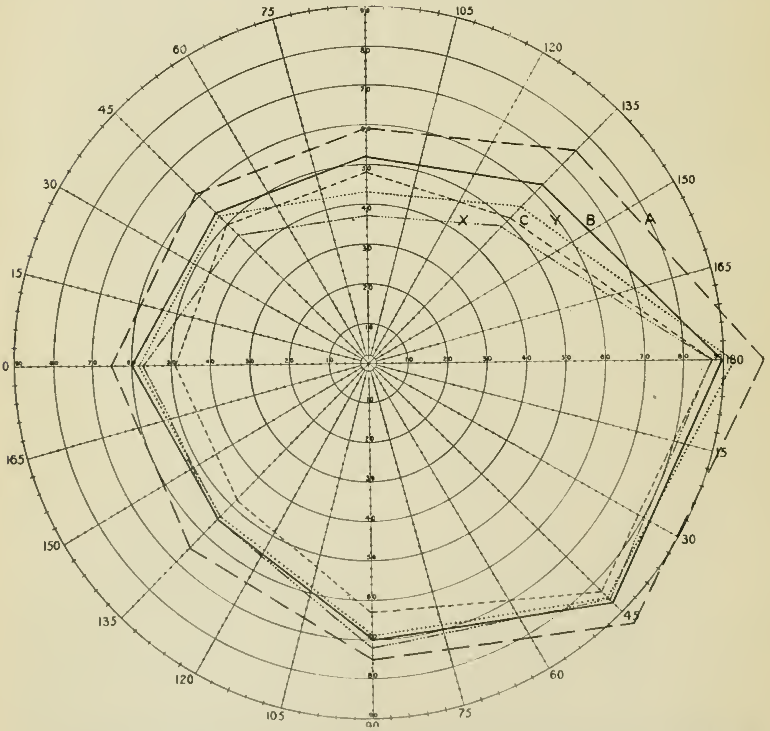

Fig. 3. Showing the widest field A, for 200 nonpathologic cases; the average field B; the narrowest field C; and the sizes of field which may be regarded as borderline, X myopes and Y emmetropes and hyperopes.

the results to vary from eye to eye. This degree of control has not yet been secured and in all probability can never be secured. At present the outstanding problem in perimetry, therefore, is diagnosis.

The first step in diagnosis is the differentiation of the pathologic from the nonpathologic eye. In case of the form field this differentiation is based on two phenomena: changes in the size or extent of field and changes in the shape of field. Size of field, it is obvious, is more affected by the nonpathologic factors which vary from eye to eye than is shape of field. The effect of these factors on size of field is to increase the range of variation for the nonpathologic eye and the tendency to overlap the range for the pathologic eye. For example, the amount of contraction of field produced by a defect or refraction in a nonpathologic eye may be as great or even greater than that produced by an incipient pathologic condition in an emmetropic eye. In the use of perimetry for diagnosis it becomes necessary, therefore, to make for the nonpathologic eye a careful determination of the range of variation of field for all of the outstanding, uncontrolled variables and for as many of them separately as is possible in our present state of knowledge. The knowledge of what is an *average* field, for ex-

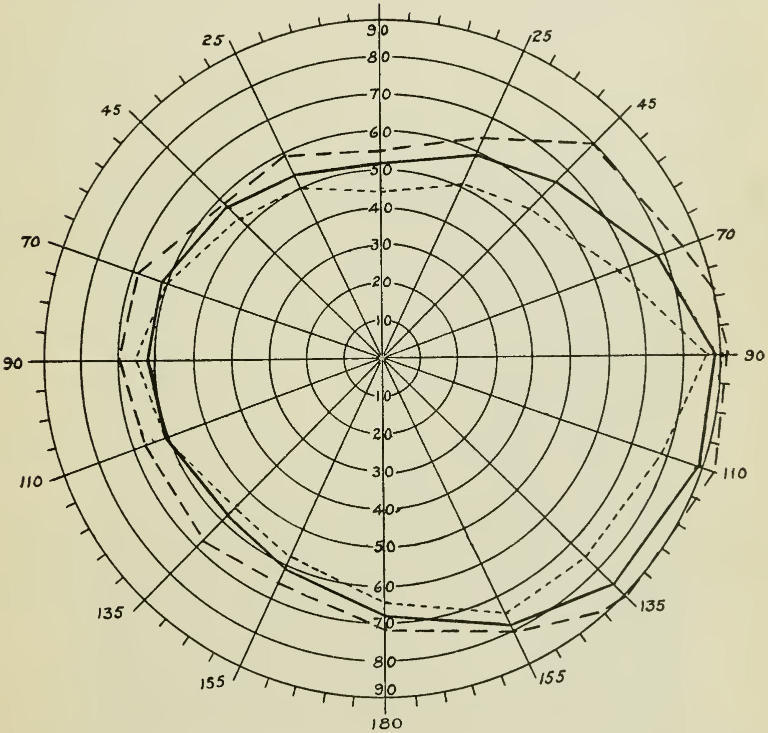

Fig. 4. Showing the widest average and narrowest fields for 15 nonpathologic cases. These observers were free from errors of refraction when tested without a cycloplegic, under 26 years of age and of normal acuity or better. The fields were taken in 16 meridians and under laboratory conditions.

ample, can contribute but little to the diagnosis of borderline cases for which the help of perimetry is most needed.

It has been the purpose of the present study to determine the range of variation of the form field for the nonpathologic eye for a stimulus subtending a visual angle of 1 degree. The cases studied were sampled to include as many as possible of the outstanding variables which are not pathologic. Two of the most important of these are age and condition of refraction. A scale has been formed showing the range of variation of field under the influence of these variables and the distribution or frequency of occurrence of the different sizes of field in a typical nonpathologic group. Such a scale provides a means of placing each new case in the class or subgroup to which it belongs rated with regard to the distribution of normal cases, i.e., it constitutes a diagnostic scale for use in the separation of pathologic from nonpathologic cases.

In the formation of this scale it has been necessary that a single value or index be chosen to represent extent of field. A number of values has been tried. Of these average breadth of field and area of field in sq. cm. of maps drawn to standard scale and measured with a planimeter were finally selected as the most feasible and satisfactory for office and clinic work.

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EFFECT OF SIZE OF STIMULUS ON SIZE AND SHAPE OF COLOR FIELDS.

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BRYN MAWR, PA.

Color fields were charted under fixed conditions of illumination, background, preexposure of the eye and standard colors, the stimulus in the different tests varying in size, so as to subtend angles of 2, 1, 0.5, and 0.17 degrees. It is found the size of the stimulus comes next in importance to its intensity in determining the boundary of the field. For red and blue the large stimulus carried boundary almost to that of the field of vision. The effect of size of stimulus and other variable factors is greater for pathologic than for normal eyes, and varies for different colors.

In previous papers[1] we have shown the effect of intensity of stimulus and of brightness of preexposure and surrounding field on the size and shape of the color fields. It will be the purpose of the present paper to show the effect of *size* or *area* of stimulus on the size and shape of the color fields.

Three possibilities may be noted as to the effect of increase in the size of the stimulus on the response of a sense organ. (1) There is an increase in the total energy of excitation in direct proportion to the increase in the size of the stimulus. If it be conceived that the receptors act collectively one might expect an increase in the response of

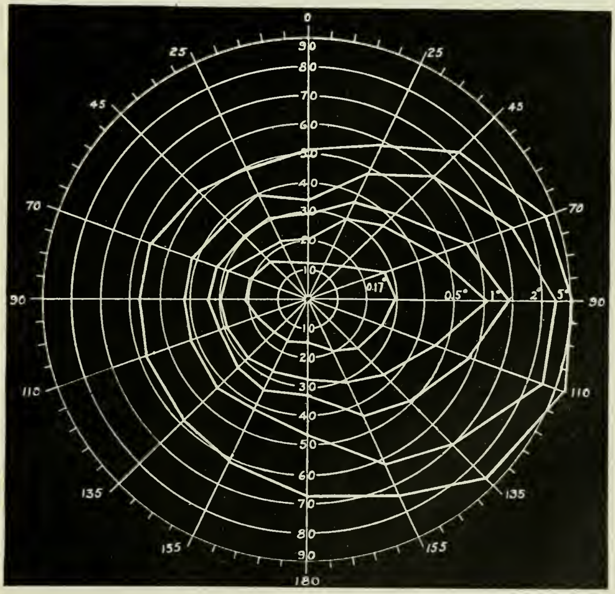

Fig. 1. Effect of size of stimulus on field for red. In this and Fig. 2 and Fig. 3 preexposure and surrounding field of grey were of same brightness as color at limits of sensitivity.

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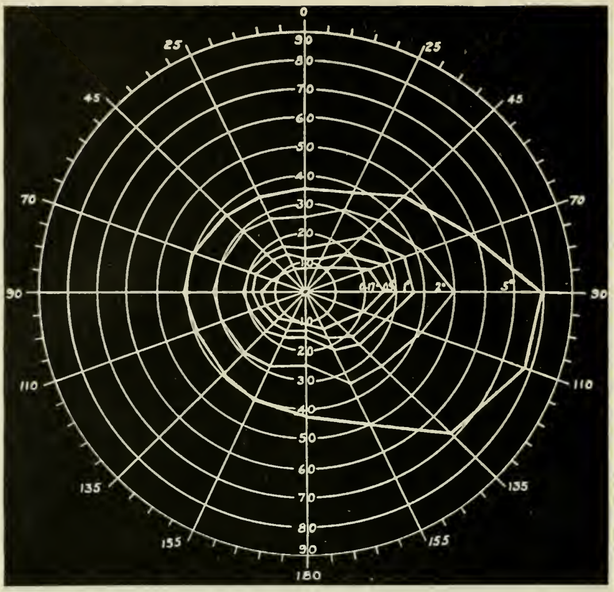

Fig. 2. Effect of size of stimulus on fields for green.

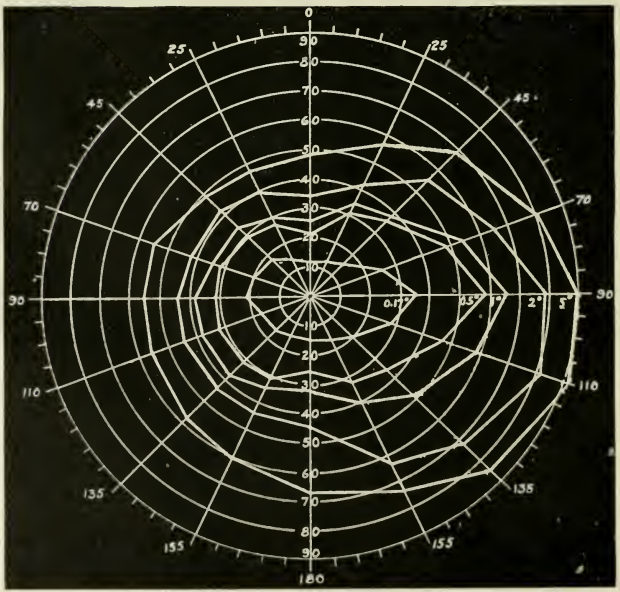

Fig. 3. Effect of size of stimulus of fields for blue.

the sense organ in direct proportion to the increase in the area of the stimulus, provided that the receptors included in the area stimulated are equally sensitive.

(2) If on the other hand it be conceived that the receptors act independently it might be expected that the intensity per unit area of stimulus, not the total intensity, would be the effective factor in determining the response of the sense organs. In this case increase of area would not increase the power of the stimulus to arouse a response in the sense organ.

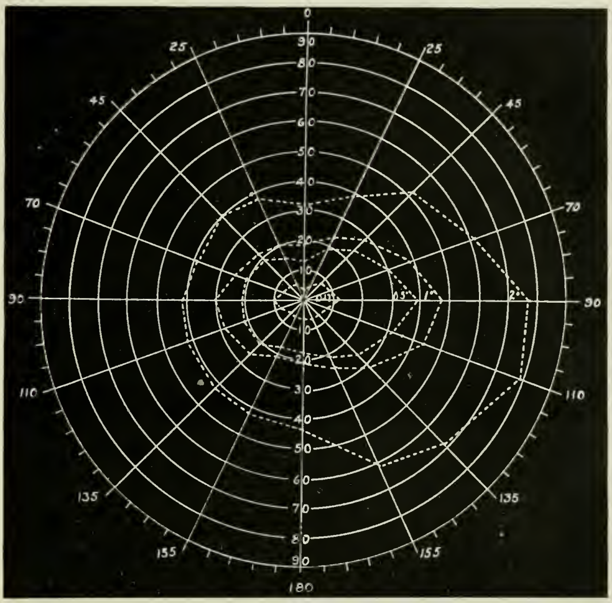

Fig. 4. Effect of size of stimulus on fields for red. For these and Fig. 5 and Fig. 6 white preexposure and surrounding field.

(3) A third view would be that increase of area is effective in arousing the response of the sense organ but that this effect is not in direct proportion to the increase of area. In a somewhat extensive study of the response of the retina made in a number of studies, we have found this latter view to be correct within limits. That is, within a certain range of change, an increase of size of stimulus increases the response of the sense organ, but apparently not in direct proportion to the change in size. Even if the first view as stated above correctly represents the law of response of nervous structures, the conditions for its fulfillment would not be found in the retina. That is, it presupposes a uniform distribution of sensitivity over the receiving surface. Uniform sensitivity occurs over very limited areas in the retina.

Next to intensity, size of stimulus is the most powerful of the extraneous factors influencing determinations of the size and shape of the color fields. Three reasons may be mentioned why the perimetrist should be thoroly familiar with this influence for all of the conditions under which it may occur. (1) Reproducibility of result can not be expected without careful control of size of stimulus. (2) No result obtained with any given size of

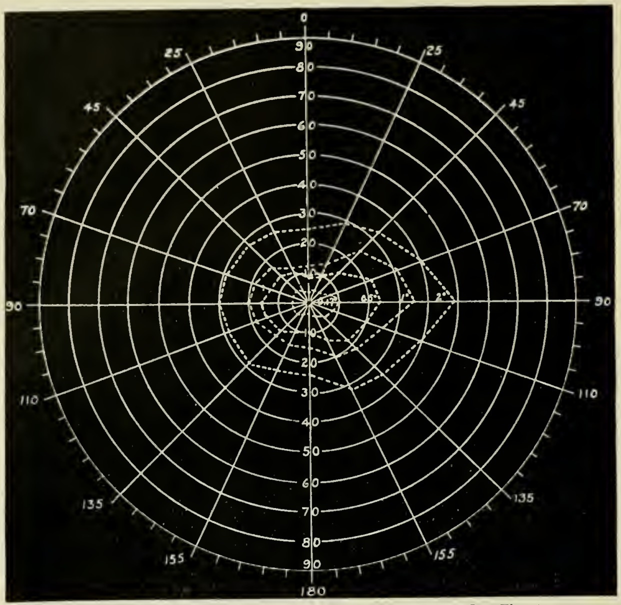

Fig. 5. Effect of size of stimulus on fields for green. See Fig. 4.

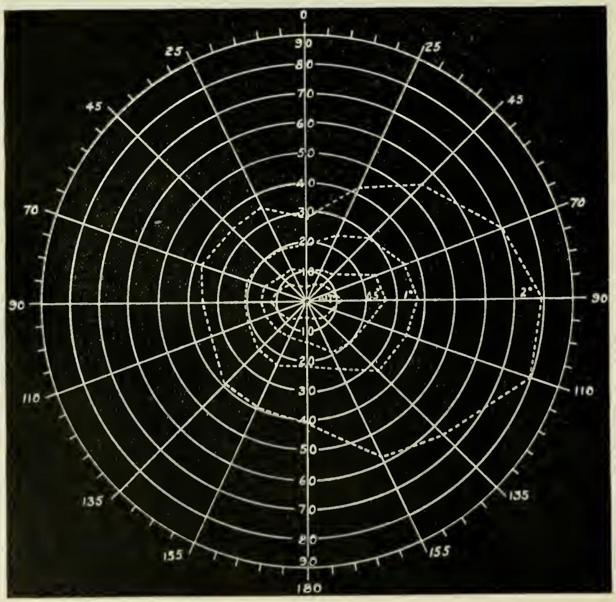

Fig. 6. Effect of size of stimulus on fields for blue See Fig. 4.

stimulus can be correctly interpreted without a knowledge of the effect of size of stimulus and of the range of variation that may be expected for nonpathologic cases with that size of stimulus. And (3) the effect of size of stimulus is greater on the size and shape of pathologic than of nonpathologic fields, *i. e.,* the pathologic field is narrowed more by the use of small stimuli than the nonpathologic field. Advantage of this fact can be taken to increase the diagnostic sensitivity in the determination of the form and color fields. Diagnostic sensitivity can be increased also by decreasing the intensity of the stimulus thru decrease of intensity of illumination, decrease of coefficient of reflection of the test object, etc., but these means are not as feasible and do not present as satisfactory working conditions as decreasing the size of the stimulus. The bearing of these points on diagnostic sensitivity will be made the subject of a later paper. It may be stated here, however, as a general principle or law of diagnosis that *any factor which decreases the response of the retina to light or color narrows the fields more for pathologic than for nonpathologic cases.* Thus in forming a diagnostic scale the amount of overlap between these two types of cases can be reduced or entirely eliminated perhaps by the use of conditions (small stimuli, low intensities, etc.) which narrow the fields. It follows also from this law that either the difference or the ratio of size of field for two sizes or two intensities of stimulus can be used as the basis of differentiation between pathologic and nonpathologic cases. A scale based on the value of this difference or this ratio would doubtless have a narrower range and involve less overlap between pathologic and nonpathologic cases than one based on the results obtained from a single size or intensity of stimulus. That is, many of

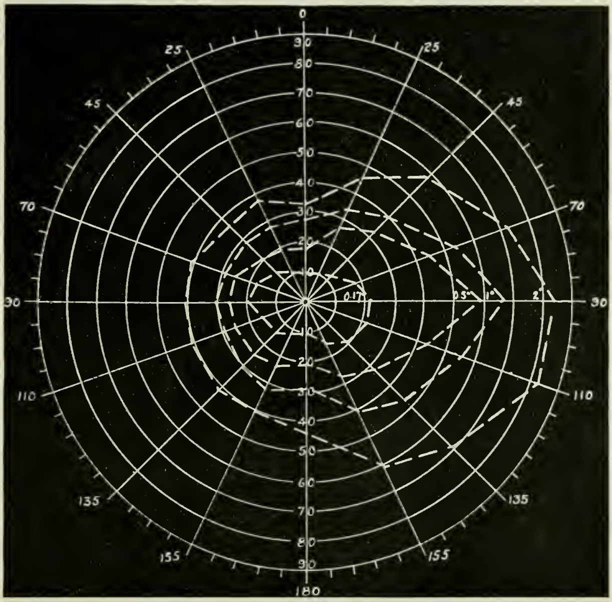

Fig. 7. Effect of size of stimulus on fields for red. Black preexposure and surroundings field for this and Figs. 8 and 9.

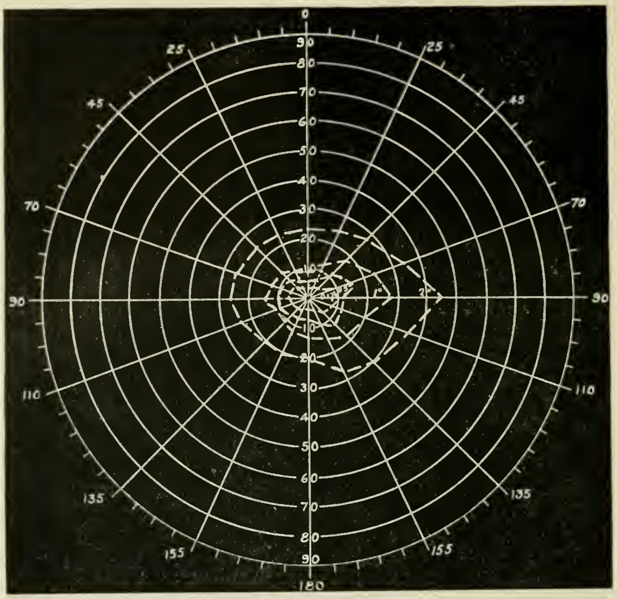

Fig. 8. Effect of size of stimulus on fields for green. See Fig. 7.

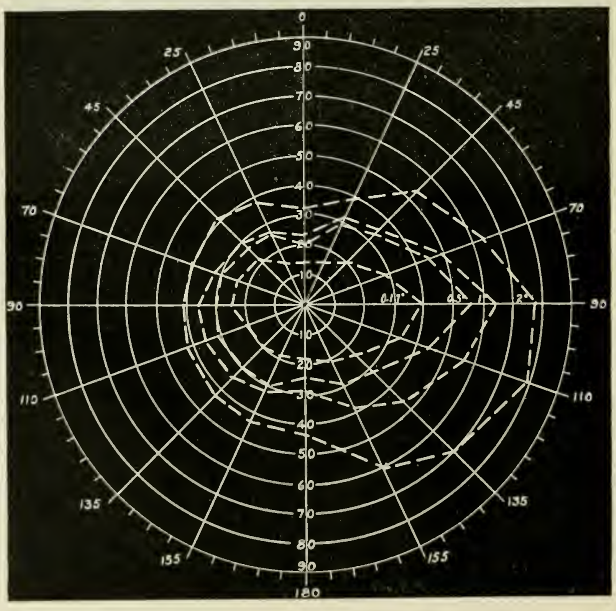

Fig. 9. Effect of size of stimulus on fields for blue. See Fig. 7.

the variable factors which influence the scatter of results from individual to individual[2] in the latter cases (age, refractive condition, shape of face, size of pupil, curvature of cornea, sensitivity of retina, etc.) would not affect the difference or the ratio of result obtained with two sizes or intensities of stimulus. It further seems probable from our results on the effect of increase of size of stimulus on extent of field that two sizes may be found which gave uniformly no difference in result for nonpathologic but do give a difference for pathologic cases. For example, the smaller of two stimuli both of which give the maximum breadth of field for the nonpathologic may produce a cut in the field for the pathologic cases. Because of the smaller size of stimulus required to give the maximum breadth of field, this procedure could doubtless be more conveniently worked out for the form than for the color fields.

It is the purpose of the present paper to show only in a general way the magnitude of the effect of size of stimulus on the limits of sensitivity when all of the other factors are subjected to careful control. In former papers we have shown that the color fields for red and blue can be made coextensive with the limits of the field of vision if a sufficiently intensive stimulus be used. One of the points included in this study has been to find out whether the same result can be obtained by increasing the area of a stimulus of good but not of excessive intensity.

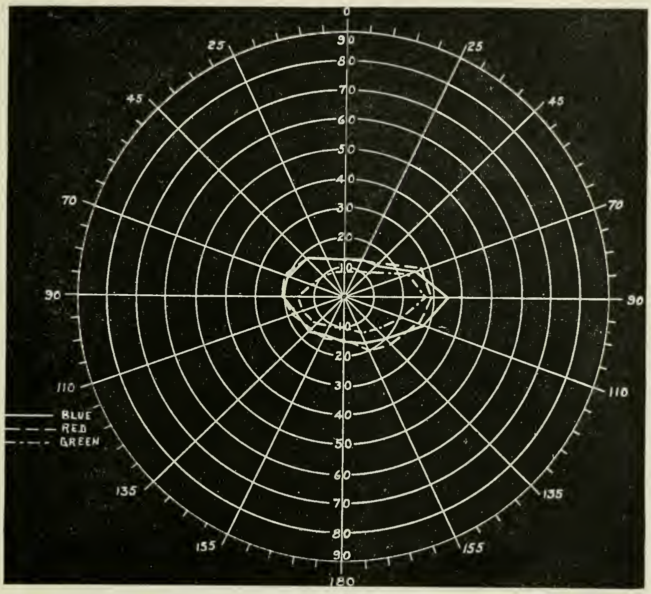

Fig. 10. Fields for red, green and blue for stimuli subtending a visual angle of 0.17 degrees. Preexposure and surrounding field of gray of brightness of stimulus at limits of sensitivity.

CONDITIONS UNDER WHICH THE WORK WAS DONE.

The determinations were made with the Ferree-Rand perimeter. The illumination of the perimeter arm was kept constant at 7 ft. c. Three brightness values were used as preexposure and surrounding field,—a white, black, and a gray of the brightness of the color at or near the point at which the limits of sensitivity occur. The brightness value of the white at the intensity of illumination employed was 0.01367 cp. per sq. in.; of the black, 0.000567 cp. per sq. in. The grays needed to match the colors in brightness were selected from the Hering series of pigment grays in which white is represented by number 1 and black by number 50. Inasmuch as the colors change their brightness when imaged at different degrees of eccentricity from the fovea, and the different sizes of stimulus carried the limits to different degrees of eccentricity in the peripheral field, different grays were required to match the different sizes of stimuli at the limits of sensitivity. In some cases also these grays varied for the different meridians for the same color. The serial number of these grays, also their brightness in candle power per square inch under the intensity of illumination used, are given in Table I. The stimuli used were a red, green and blue of the Heidelberg series of pigment papers. The sizes employed subtended a visual angle at the eye of 2, 1, 0.5 and 0.17 deg. respectively.

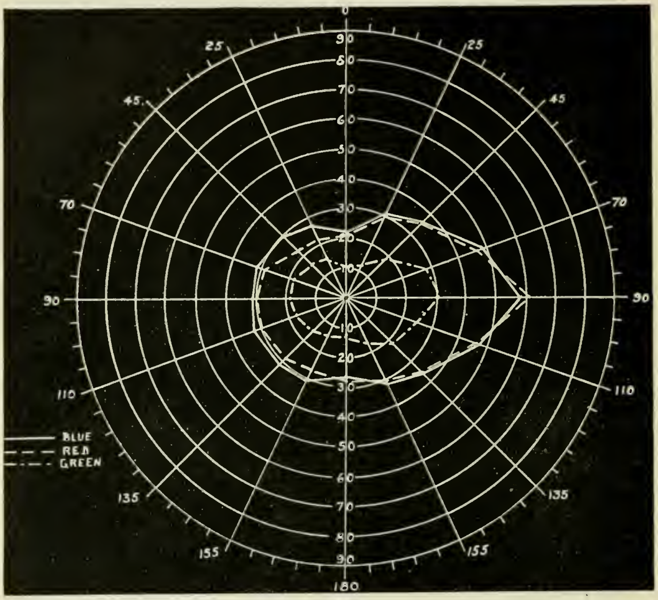

Fig. 11. Fields for red, green and blue for stimuli subtending a visual angle of 0.5 degrees. Preexposure and surrounding field of grey of brightness of color at limits of sensitivity.

As stated above, an attempt was made to find out whether the color fields could be made coextensive with the field of vision by increasing the area of stimuli of good but not excessive intensity. For this work only the gray preexposure and surrounding field was used. Various sizes of stimulus were investigated for each color. It was found that an increase in the visual angle subtended by the colored stimulus up to 5 deg. widened the limits of sensitivity to that color. An increase beyond this size widened the limits only in case the limit is defined as the angular separation of the center of the stimulus from the fovea and then only by the amount which is some approximation of half the visual angle subtended by the stimulus. The limits of sensitivity were therefore determined for this optimum size of stimulus, 5 deg., in order to show the widest fields that could be obtained for our observer by increasing the area for the intensity of stimulus employed. For comparison the form field for a 1 deg. white stimulus on a black background was also determined.

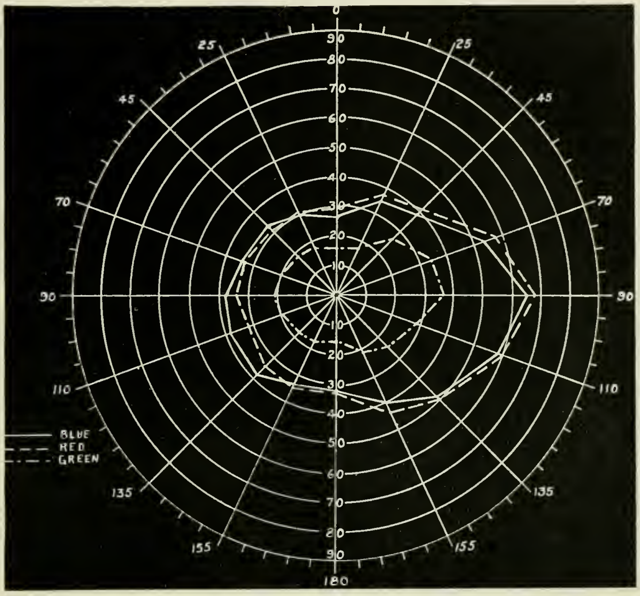

Fig. 12. Fields for red, green and blue for stimuli subtending a visual angle of 1 degree. Preexposure and surrounding field of gray of brightness of color at limits of sensitivity.

In specifying the limits of sensitivity for stimuli of different area, two methods may be employed.[3] (1) The usual method may be followed of specifying the limit by the angular separation between the fovea and the center of the stimulus when it is placed at the point at which all trace of its original quality is lost. Or (2) the limit may be defined as the angular separation between the fovea and the inner edge of the stimulus when it is placed at the point at which all trace of its original quality is lost. The degrees of eccentricity given by the two methods differ then by one-half the visual angle subtended by the stimulus. In this paper we have specified the limits of sensitivity in accordance with the first of the above mentioned methods. The difference for the methods would be negligible for our results in case of the stimuli subtending visual angles of 0.17, 0.5 and 1 deg. For the stimuli subtending visual angles of 2 and 5 deg., the limits are wider by 1 and 2.5 deg. respectively as we have specified them than they would be by the second method.

RESULTS.

The results obtained are shown in Tables II-IV and Figs. 1-14.

A precise way of making a quantitative comparison of fields for the sake of determining numerically the exact effect of any given factor, is to measure the areas of the fields plotted to a standard scale and determine the relations of these areas. The measurements can be made most conveniently by means of a planimeter. The perimetrist will find this instrument of great value and convenience in compiling and interpreting his results. We have measured the areas of the fields shown in Figs. 1-14 when plotted to a scale of 1 mm. to 1 deg. of visual angle, and have determined in per cent the amount the field has been changed by each of the sizes of stimulus for the three conditions of preexposure and surrounding field, using the area of the field determined with the 2 deg. stimulus as the base on which to compute the percentage change. In Table II are given the area of the fields in sq. cm. when plotted to a scale of 1 mm. to 1 deg. for the different sizes of stimuli for the different preexposures and surrounding fields. In Table III are shown in percent the reductions in area of the color fields for stimuli of respectively 1 deg., 0.5 deg. and 0.17 deg. as compared with a stimulus of 2 deg. In Table IV a comparison is made of the area of field for the three colors with a 5 deg. stimulus with that of the form field (white on black) with a 1 deg. stimulus.

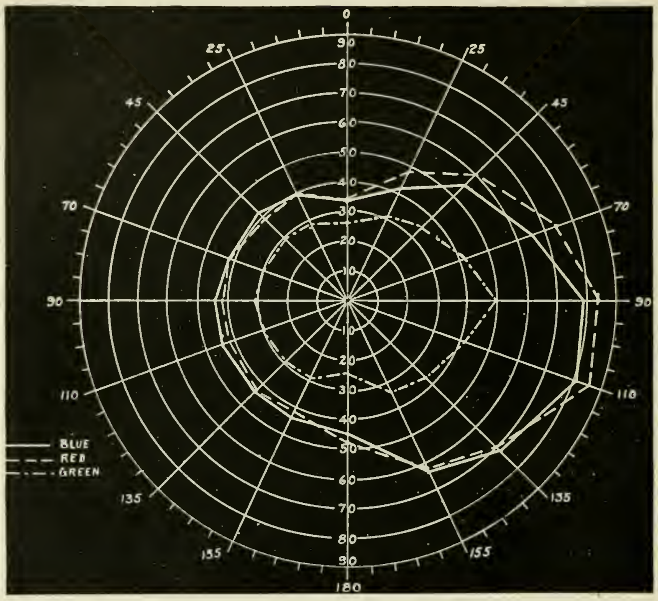

Fig. 13. Fields for red, green and blue for stimuli subtending a visual angle of 2 degrees. Preexposure and surrounding field of grey of brightness of color at limits of sensitivity.

In Figs. 1-3 are shown the fields for each color for all sizes of stimulus used for the gray preexposure and surrounding field; in Figs. 4-6 for the black preexposure and surrounding field; and in Figs. 7-9 for the white preexposure and surrounding fields. In Figs. 10-13 are shown the fields for the three colors taken respectively with 2, 1, 0.5 and 0.17 deg. stimuli with preexposure and surrounding field in every case of the gray of the brightness of the color; and in Fig. 14, the fields for the three colors with a 5 deg. stimulus (gray preexposure and surrounding field) and for the form field (white on black) with a 1 deg. stimulus.

SUMMARY.

The results obtained may be briefly summarized as follows: (1) Size of stimulus is a powerful determinant of the visibility of color in the peripheral field, comparable with intensity in importance.

(2) By increase of size of stimulus the limits of sensitivity to red and blue for stimuli of the intensity employed can be made almost coextensive with the limits of the field of vision. With stimuli subtending a visual angle of 5 deg. illuminated by 7 ft. c. of light, the fields for red were only 6 and for blue only 11 per cent smaller than for a 1 deg. stimulus of white on black. Further increase in size of the colored stimulus for this intensity of illumination did not seem materially to increase the extent of the field. As has been demonstrated in former papers the limits of these colors with higher intensities of stimulation are coextensive with the limits of the field of vision for stimuli much smaller than 5 deg. It was one of the purposes of this paper to see whether this result could be accomplished by increasing the size of stimuli of moderate intensity.

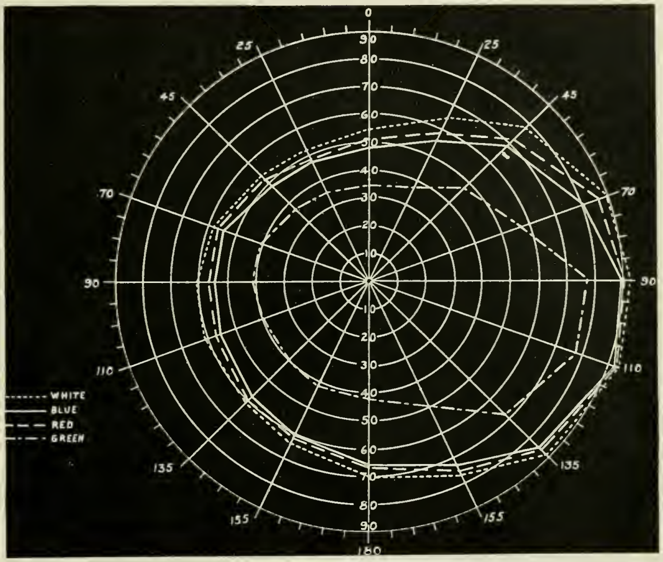

Fig. 14. Fields for red, green and blue for stimuli of optimum size (5 degrees); and for the form field (white stimulus on black, 1 degree). Preexposure and surrounding field of gray of brightness of color at limits of sensitivity.

(3) Size of stimulus produced the least effect with a preexposure and surrounding field of the brightness of the color. The effect, as might be expected, was considerably greater for the white and black preexposures and surrounding fields. So far as we have been able to determine, the effect of any factor, nonpathologic or pathologic, is greater in the presence of other factors than when the influence of these factors is eliminated. This fact may contain a suggestion as to methods of increasing diagnostic sensitivity. Any use of a factor for that purpose, however, presupposes the standardization of its influence. Also, to be differential or of value for diagnosis, the effect must be greater on the pathologic than on the nonpathologic eye. This in general seems to be the case.

(4) The effect of size of stimulus in the presence of brightness difference between stimulus and preexposure and surrounding field is shown in Table II to be some unknown relation to the magnitude of that difference. That is, the effect in case of blue and red (the darker colors) was considerably

TABLE I.

Showing the serial numbers and brightnesses in cp. per sq. in.[1] under 7 ft. c. of illumination of the gray pigments (Hering series) which matched the different sizes of stimuli at the limits of eccentricity.

Visual angle (deg.)	Red		Green		Blue	
	Serial number	Cp. per sq. in.	Serial number	Cp. per sq. in.	Serial number	Cp. per sq. in.
5	41	.00127	6	.00651	29	.00214
2	41	.00127	6 3	.00651 .00883	33 31	.00177 .00195
1	33	.00177	7	.00613	33	.00177
0.5	41	.00127	7	.00613	29	.00214
0.17	39	.00161	5	.00682	29	.00214

greater for the white preexposure and surrounding field and for green (the lightest color) with the black preexposure and surrounding field. A comparison of the coefficients of reflection of the grays which match these colors in brightness with those for the white and black used will show that the brightness difference between green and black and between red and blue and white was greatest.

(5) The decrease in the size of field produced by decreasing the size of the stimulus was, with the exception of blue with the 0.17 deg. stimulus for the white surrounding field and preexposure, greater for red than for blue.

TABLE II.

Showing the effect of size of stimulus on the area in sq. cm. of the color fields for red, green and blue stimuli with preexposures and surrounding fields respectively of black, white and the gray of the brightness of the color at the limits of sensitivity.

Color	Area in sq. cm. of color field for			
	2 deg.	1 deg.	0.5 deg.	0.17deg.
Gray preexposure and surrounding field				
Red...........	99.3	56.4	37.4	12.6
Green.........	36.0	16.8	11.4	6.5
Blue...........	94.2	54.6	40.25	12.5
White preexposure and surrounding field				
Red...........	82.5	22.3	9.2	2.0
Green.........	33.3	13.1	7.5	2.5
Blue...........	85.6	27.0	17.9	2.5
Black preexposure and surrounding field				
Red...........	92.5	48.8	30.0	8.2
Green.........	25.0	8.2	3.2	1.1
Blue...........	88.1	48.4	34.8	17.8

TABLE III.

Showing in percent the reduction in area of the color field when stimuli of 1 deg., 0.5 deg. and 0.17 deg. respectively are used as compared with the area for a stimulus of 2 deg. Colors: red, green and blue. Preexposures and surrounding fields: black, white and gray of the brightness of the color at the limits of sensitivity.

Color	Percent reduction in area from the field for the 2 deg. stimulus for		
	1 deg. stimulus	0.5 deg. stimulus	0.17 deg. stimulus
Gray preexposure and surrounding field			
Red........	43.2	62.3	87.3
Green......	53.3	68.3	81.9
Blue........	42.0	57.3	86.7
White preexposure and surrounding field			
Red........	73.0	88.9	97.6
Green......	60.7	77.5	92.5
Blue........	68.5	79.1	97.1
Black preexposure and surrounding field			
Red........	47.2	67.6	91.1
Green......	67.2	87.2	95.6
Blue........	45.1	60.5	79.9

TABLE IV.

Showing for comparison the area in sq. cm. of the color fields for the optimum size of stimulus and of the form field (white on black) for a 1 deg. stimulus. Size of colored stimulus, 5 deg.; preexposure and surrounding field, gray of the brightness of the color at the limits of sensitivity.

Stimulus	Size of stimulus	Area of field (sq. cm.)
Red	5 deg.	156.5
Green	5 deg.	77.4
Blue	5 deg.	147.3
White	1 deg.	166.0

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[1] Values specified in candle power per square inch may be converted into millilamberts by multiplying by 486.8.

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STUDIES IN PERIMETRY: 2, PRELIMINARY WORK ON A DIAGNOSTIC SCALE FOR THE COLOR FIELDS

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A previous paper had plotted the range of variation of the form field for two hundred nonpathologic cases, classified as emmetropic, myopic, hyperopic, presbyopic, and astigmatic, at ages from eight to fifty-five years. The present paper undertakes to provide a similar determination of standard variations for the color fields, studied in 126 cases. Reasons are given to explain why the color fields show a greater range of variation than the form field. For the color fields the average breadth of field was considerably less in the clinic than in the laboratory study, and the range was considerably greater.

Introduction

The diagnosis of a pathologic condition in the presence of variables which are not pathologic necessitates one of two procedures: (a) the influence of the nonpathologic factors must be eliminated; or (b) a scale must be formed showing the normal range of variation of results under the influence of these factors. The determination of the color fields is influenced by many factors which are not pathologic. These may be divided into two classes: those pertaining to a given eye and those which differ from individual to individual. Among those of the former class the following may be mentioned: wave-length and purity of stimulus, intensity of stimulus, size of stimulus or angle subtended at the eye, length of exposure to stimulus, method of exposure (moving or stationary stimulus), intensity of general illumination of the retina and the state of adaptation, breadth of pupil, and brightness of preexposure and of background or surrounding field. To these may be added also method of approach of the limit (ascending or descending series) and method of judging the limit for colors which change in hue in passing to the periphery of the field, e.g., red and green.

Methods and devices have been provided for the control of these factors with a high degree of precision. The study of the course of a pathologic condition in a given eye can thus be made with a satisfactory degree of certainty. Many factors of the second group, however, are in all probability not amenable to control by any means feasible for application in practical work. In dealing with these factors we are forced, therefore, to adopt the latter and less satisfactory of the two procedures referred to above. That is, a scale must be formed showing a typical distribution of results for nonpathologic cases, under the influence of the factors that can not be controlled. In forming such a scale it is very desirable also that the results be classified and grouped with reference to as many factors as possible separately. We thus know what range of variation to expect from nonpathologic myopes, hyperopes, or presbyopes, observers falling within a certain range of central color sensitivity, and so on.

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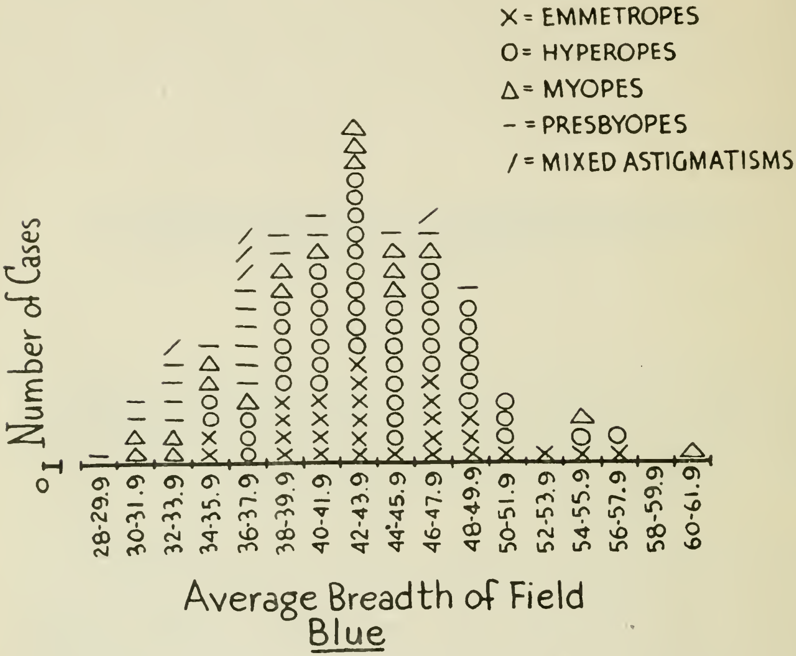

Fig. 1 (Ferree, Rand, and Monroe). Average breadth of field for the blue stimulus; showing the distribution for 126 nonpathological cases. The observers for this and the two following charts were selected to include cases of emmetropia, hyperopia, myopia, presbyopia, and mixed astigmatism. The distribution is based on the average breadth of field in the eight principal meridians. Average breadth of field in degrees is plotted on the horizontal coordinate, and number of cases on the vertical coordinate.

The effect of variable factors is, of course, to extend the normal range of variation and to render the use of differences in size of field less sensitive and less certain as a means of diagnosing incipient and borderline cases. A special study is being made of these effects and a great deal of valuable information has already been obtained. Among the measurable factors the effects of which are being studied may be mentioned curvature of cornea, breadth of pupil, the peripheral refractive conditions, and peripheral acuity. Although there is little reason to expect that change of size of field can ever be made as sensitive and satisfactory a means of diagnosis as change of shape, still it is our hope that important improvements may be made, particularly for the sake of those pathologic conditions in which change of shape is not a prominent feature.

An important need in establishing the borderline between pathologic and nonpathologic fields is that a careful record be kept of the cases examined in order that follow-up work may be done. If the borderline between what is pathologic and what is normal is to be decided entirely by the results of objective examination, a limit is placed on the sensitivity and usefulness of the subjective method. Careful follow-up work on the cases examined should be a valuable aid in determining the true borderline and in making the subjective method of examination a more independent and serviceable factor in diagnosis. Provision has been made for this in the work that is reported in this series of papers.

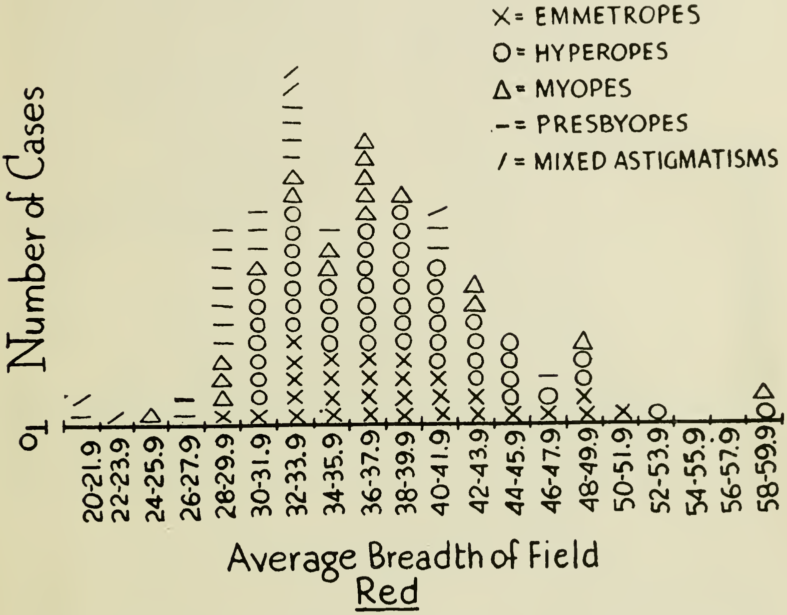

Fig. 2 (Ferree, Rand, and Monroe). Average breadth of field for the red stimulus: showing the distribution for 126 nonpathological cases.

Conditions under which the fields were taken

In the first paper of this series[1] data were presented showing the range of variation of the form field for two hundred nonpathologic cases when a white stimulus subtending a visual angle of one degree was used and the illumination was kept constant at seven foot-candles at every point in the field. In this work a careful control was exercised over all of the external factors affecting the results of the determinations. With reference to the factors which influence the results from individual to individual, however, the selection of cases with two important exceptions, age and condition of refraction, was left entirely to chance. This was done because of the lack of definite knowledge of their relative importance. In the group of observers used were included cases of emmetropia, myopia, hyperopia, presbyopia, and astigmatism. The range of age was from eight to fifty-five years. For convenience of comparison an index had to be chosen to represent size of field. Two types of index were used: the average breadth of field in the eight principal meridians, and the area of the field, mapped on a scale of 12 mm. to 10°, measured with a planimeter. The results obtained were plotted in the form of graphs showing the frequency distribution of cases around a mid or median value. From an inspection of these graphs can be determined, therefore, the widest, narrowest, and average field for all or any of the five classes of observers used and the size of field that should be regarded as borderline or suspicious.

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[1] Studies in perimetry: I, Preliminary work on a diagnostic scale for the form field. Amer. Jour. Ophth., 1926, v. 9, 95-104.

It was the purpose of the present study to make the same type of determination for the color fields as was made in the previous study for the form field, using the same observers. For various reasons, however, only 126 of these observers could be used. The determinations were made with the Ferree-Rand perimeter. The stimuli employed were the standard red, green and blue of the Heidelberg series of pigment papers. From the standpoint of hue, saturation, coefficient of reflection, composition of light reflected, and durability these pigments were selected as the most suitable for clinic work of any that are now available for extensive use. The size of the stimulus was such as to subtend an angle of one degree at the eye of the observer. The pre-

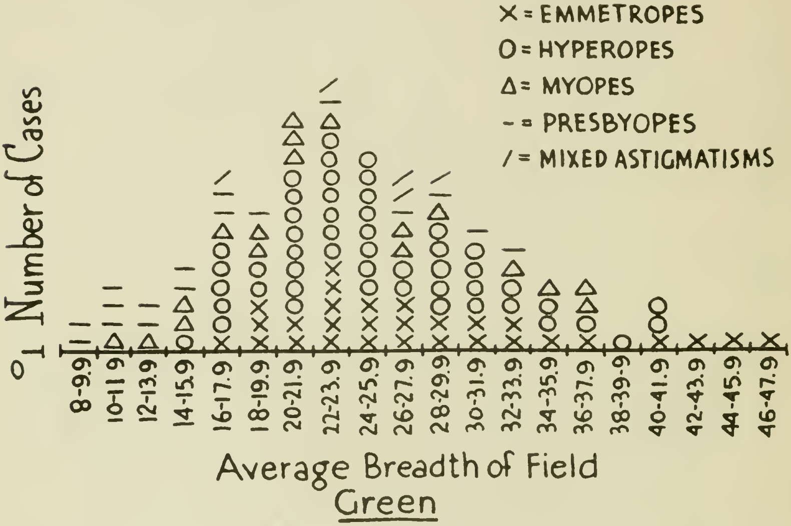

Fig. 3 (Ferree, Rand, and Monroe). Average breadth of field for the green stimulus; showing the distribution for 119 nonpathological cases.

exposure and surrounding field were in each case made as nearly as possible equal in brightness to the color at the limits of sensitivity. For this purpose the perimeter used is provided with preexposure and stimulus screens of a suitable coefficient of reflection. The value of this coefficient for the screens prepared for the blue and red stimuli is 11.4 per cent and for the green stimulus 39.5 per cent. The brightnesses of these screens when illuminated with seven foot-candles of light are respectively 0.00177 candle power per square inch and 0.00613 candle power per square inch.

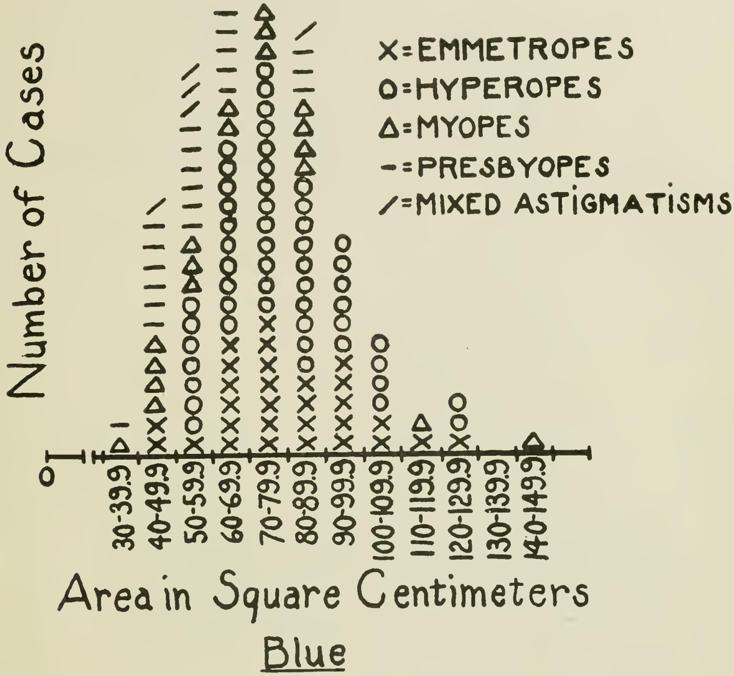

Fig. 4 (Ferree, Rand, and Monroe). Area of field for the blue stimulus; showing the distribution for 126 nonpathological cases. The observers for this and the two following charts were selected to include cases of emmetropia, hyperopia, myopia, presbyopia, and mixed astigmatism. The distribution is based on the area of field as measured with a planimeter from maps drawn to a scale of one degree to 1.2 mm. Area of field is plotted on the horizontal coordinate, and number of cases on the vertical coordinate.

As has been demonstrated in former papers, it is very important in the determination of the color fields to have a constant illumination of the stimulus and no difference in brightness between it and the surfaces which serve as preexposure and surrounding field. This latter control, it will be remembered, accomplishes two purposes: (a) It eliminates all variable effects due to brightness after-image and to brightness induction from the surrounding field on the power of the retina to respond to color; and (b) it renders the judgment of the limit more certain and easier to make, since at the limit of sensitivity the stimulus becomes indistinguishable from the background when the background is of the same brightness as the color. The determinations were made in the eight principal meridians (0, 45, 90, 135, 180, 225, 270, and 315 degrees)*. Ample rest periods were allowed between ob-

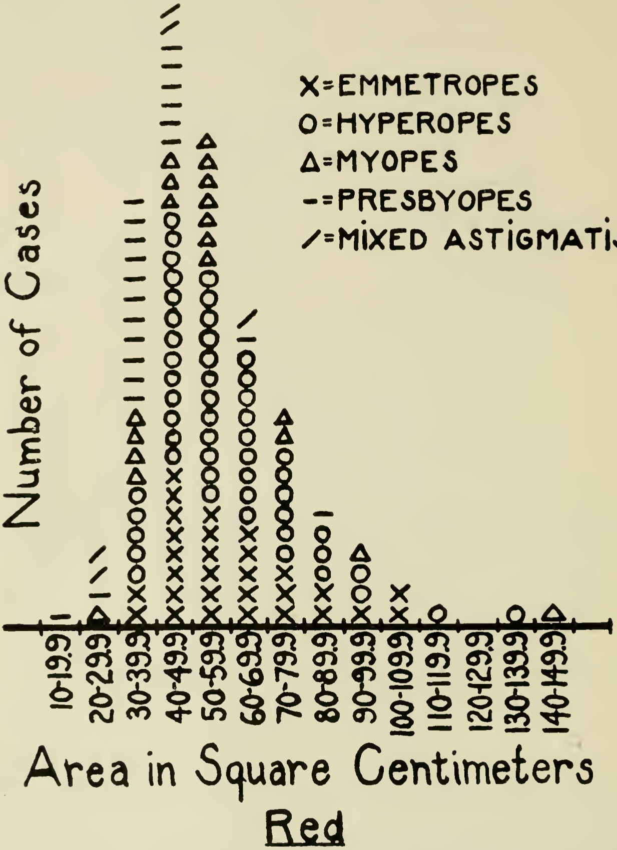

Fig. 5 (Ferree, Rand, and Monroe). Area of field for the red stimulus; showing the distribution for 119 nonpathological cases.

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* As in former papers, the term meridian is used here for the quadrant of the meridian. While it is not necessary in refraction to treat the two anterior quadrants of the meridian separately, there is need for the separate treatment in perimetry.

Since the situation and needs in perimetry and refraction are so different, there seems intrinsically to be no good reason why the same designation should be used in the two cases. It might be advisable and convenient in perimetry to adopt the term quadrant and to number the quadrants for the right eye counterclockwise from 0, right horizontal, to but not including 360 degrees; and for the left eye clockwise from 0, left horizontal, to but not including 360 degrees. By this method the quadrant designations would correspond throughout for the two eyes, i.e., 45 degrees would represent upper temporal, 135 degrees upper nasal, and so on, for both eyes; but two sets of maps would be required, one for the right eye and one for the left. Similarly two concentric sets of graduations would be needed on the dial of the perimeter, one numbered clockwise for the right eye, the other counterclockwise for the left eye.

servations. Each determination was carefully checked, but the observers were not given extensive preliminary training. Care was taken not to include in the series the results of any observer showing a pathologic condition by objective examination. The observers were required also to pass the Ishihara test for color-blindness.

The results obtained may be considered to represent a fair sample of the color fields that may be expected from an average group of untrained observers showing no pathology, when the work is done under the conditions described above. These conditions, with regard to number of meridians selected, the preliminary training of the observer, the time consumed in making the examination, and so on, were intended more nearly to approximate those of the clinic than of the laboratory. Whether this was wise or not remains yet to be seen. The range of variation of fields obtained under such conditions of examination is not in all respects encouraging. How much of this is due to the attempt to conform to certain aspects of clinic condition and how much of it could have been avoided by a more careful and time-consuming examination can not be determined at this time.

The following reasons may be given for the greater range of variation of the color fields than of the form field:

(1) The color fields demand a much more careful method of working than the form field. The success of the examination is also much more dependent on the intelligence of the observer, the instructions received, and the amount of preliminary training and practice that is given. Practice in making the judgment of color is without question a very important factor. The results are more dependent too on the skill and experience of the operator and his intelligent understanding of the characteristics of the chromatic response of the peripheral retina and the factors by which it is influenced. The difference between the methodologic problem set by the two types of determination can not be too strongly emphasized at this point.

(2) The color fields are much more sensitive to conditions which may influence the results, both pathologic and nonpathologic, than the form fields. This superior sensitivity gives them much greater possibilities as a means of diagnosis and investigation, but it also makes them more difficult to use. A sensitive instrument, for example, because of its sensitivity, is apt to be erratic. The satisfactory use of such an instrument in the hands of a novice is impossible. When used by a skilled operator, however, and properly protected from the influence of extraneous factors, it has an advantage and degree of usefulness in direct proportion to its sensitivity.

(3) The color fields are more subject to variation due to individual differences than the form field. All of the factors which differ from individual to individual have in general more effect on the color fields than on the form field because of the difference in sensitivity just noted. In addition there are greater individual differences in chromatic than achromatic sensitivity and greater deviations in its irregularity of distribution over the retina. Central color sensitivity has been found to sustain such an important relation to breadth of field in the nonpathologic eye that it may well be that the diagnostic scale should be formed and used in conjunction with tests for central sensitivity. That is, by means of the two scales determined for the same observers, one showing the normal range and distribution of breadth of field, we should have not only a twofold check on diagnosis, but a scale of relations, disturbances of which might have an important diagnostic significance. The relative amounts of effect on central and peripheral sensitivity may, for example, prove

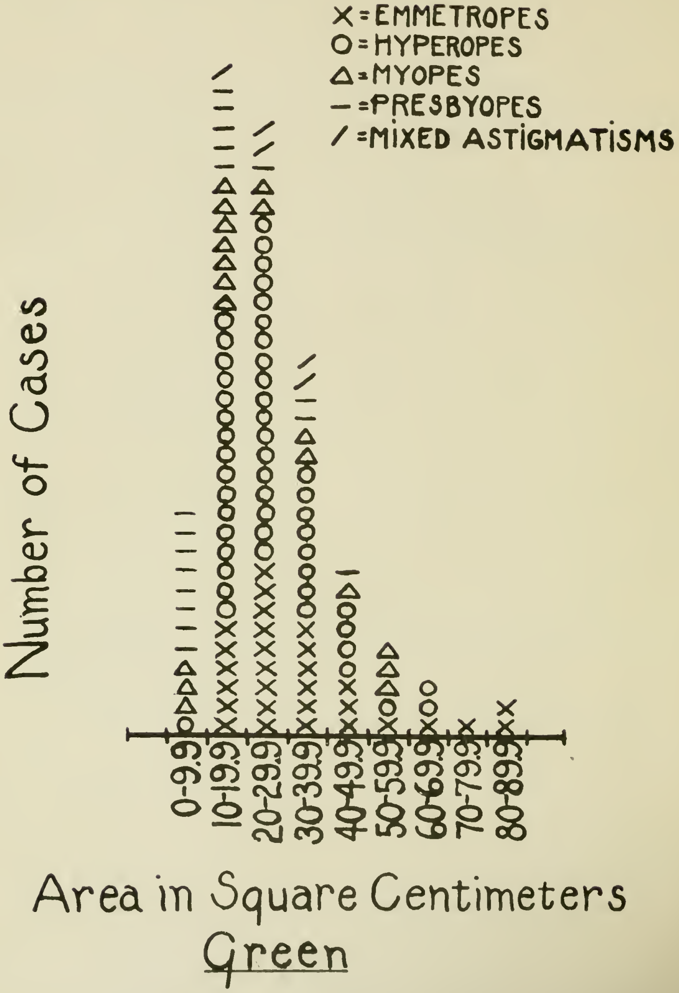

Fig. 6 (Ferree, Rand, and Monroe). Area of field for the green stimulus; showing the distribution for 119 nonpathological cases.

to be an important aid in differentiating between health and disease and between the various pathologic conditions.

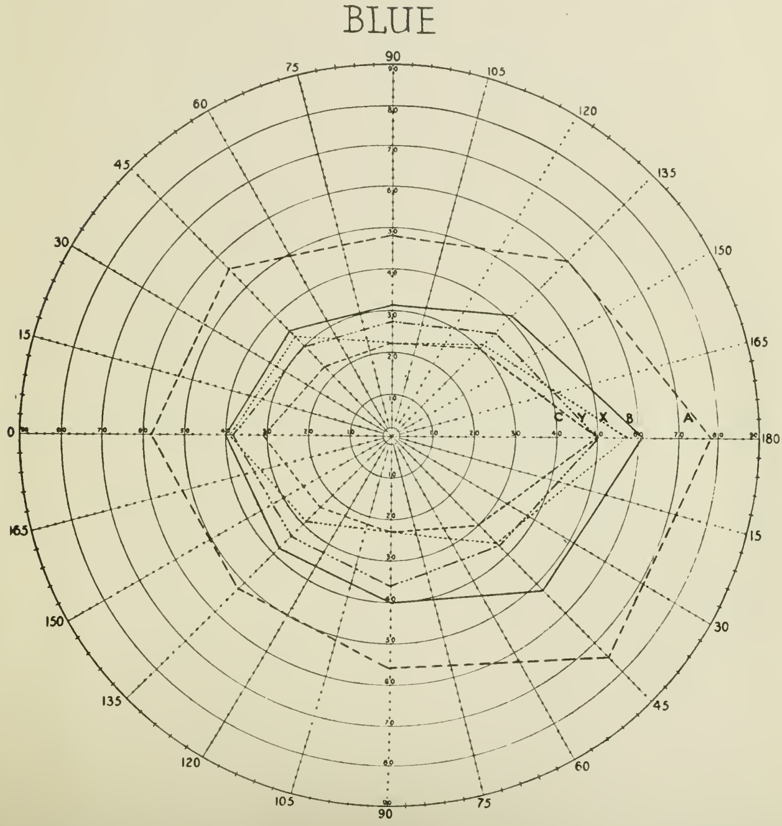

Fig. 7 (Ferree, Rand, and Monroe). Fields for blue; showing the widest field, A, for 126 nonpathological cases; the average field, B; the narrowest field, C; and the sizes of field which may be regarded as borderline, X for myopes and presbyopes, Y for emmetropes and hyperopes.

(4) The use of a small stimulus increases the sensitivity of the perimetric method more for the color than for the form stimulus. Proportionally greater facility is thus given to color perimetry for picking up differences between observers. This furnishes an additional reason for expecting a greater scatter of results for a one degree color than for a one degree form stimulus. It may yet be found to be of advantage in the case of color to use a larger stimulus (e.g., two degrees) for diagnostic work based on size of field and to employ small stimuli and other devices for increasing sensitivity only for the detection of scotomata, regional cuts, and so on, and for checking up the advance and recession of a pathologi-

cal condition, in which cases the increased sensitivity entails no compensating handicaps.

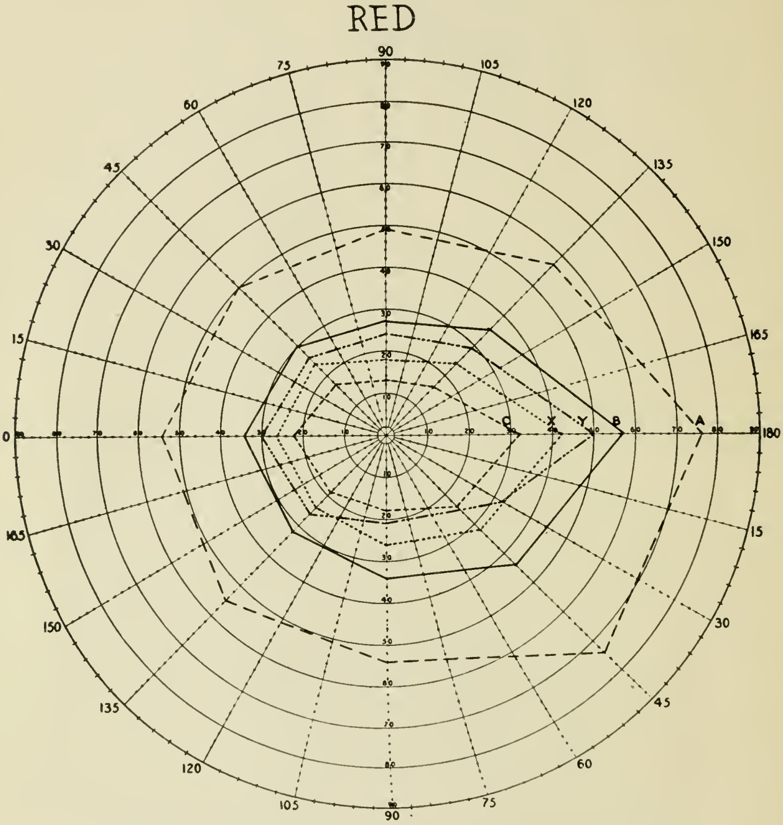

Fig. 8 (Ferree, Rand, and Monroe). Fields for red; showing the widest field, A, for 126 nonpathological cases; the average field, B; the narrowest field, C; and the sizes of field which may be regarded as borderline, X for myopes and presbyopes, Y for emmetropes and hyperopes.

It is obvious that much has yet to be done for color perimetry before it can be given maximum serviceability in diagnosis so far as extent of field is concerned. Results are presented at this time, in part to serve as a tentative scale until a more thorough study can be made of the factors which differ from individual to individual, and in part by way of admonition to show what may be expected as to the normal range of variation of field when taken under conditions which approximate those found in the clinic, even when all external conditions known to influence the results are carefully controlled.

In this connection, it scarcely need be pointed out that the value of a scale for diagnosis does not depend upon the normal range of variation alone, but upon this range in relation to the pathologic range. A large normal range is of consequence only in so far as it increases the liability to overlapping with the pathologic range. Data on this point will be presented in a later paper.

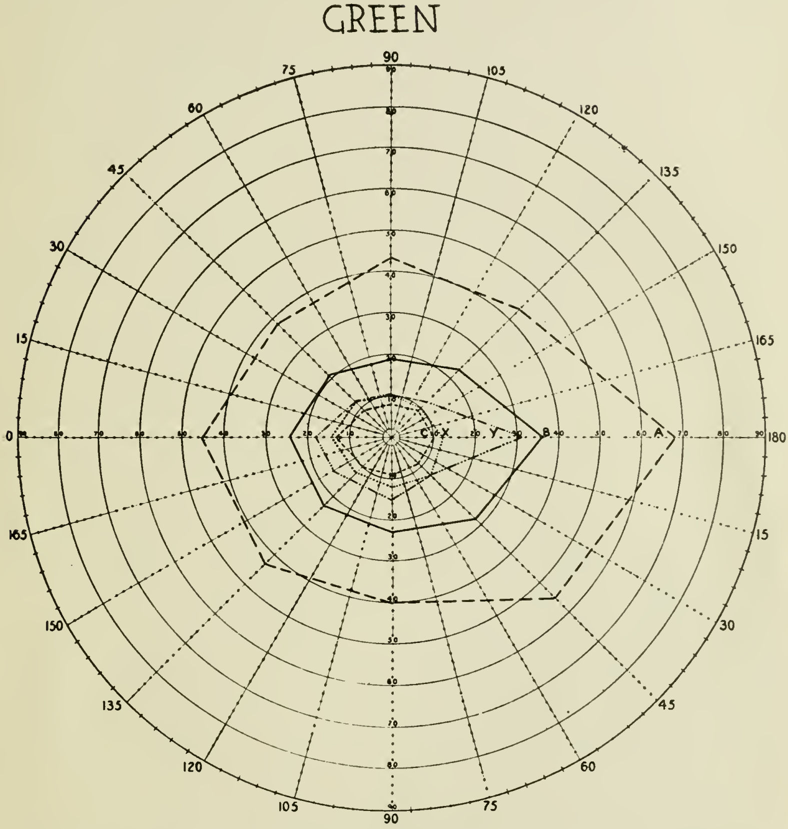
GREEN

Fig. 9 (Ferree, Rand, and Monroe). Fields for green; showing the widest field, A, for 119 nonpathological cases; the average field, B; the narrowest field, C; and the sizes of field which may be regarded as borderline, X for myopes and presbyopes, Y for emmetropes and hyperopes.

Results

The fields for red and blue were taken for 126 eyes. Of these 52 were hyperopes, 19 were myopes, 21 were presbyopes, 5 had mixed astigmatism, and 29 showed no error of refraction or an error no greater than one diopter of hyperopia or 0.25 diopter of hyperopic astigmatism. For convenience of treatment this latter group will be referred to as emmetropic, The field for green was determined for 119 eyes. Of these 50 were hyperopes, 18 were myopes, 17 were presbyopes, 5 had mixed astigmatism, and 29 showed not more than one diopter of hyperopia or 0.25 diopter of hyperopic astigmatism. The range of age was from eight to fifty-five years. A graphic representation of the distribution of cases is given in figures 1 to 6. The representation in figures 1 to 3 is based on the average breadth of field in the eight principal meridians; in figures 4 to 6 on the area of field mapped to scale, measured with a planimeter. In these representations the results are arranged in groups, the range of each group for the former case being two degrees and for the latter ten square centimeters. In these groups the cases are designated with regard to condition of refraction according to a key shown in the charts.

The results may be summarized as follows:

(1) In general the emmetropes and hyperopes have the wider fields, the myopes and presbyopes the narrower fields. However, the tendency for the separation into the two groups is not so clearly marked for the color fields as for the form field. Considering the refraction groups separately, we find in general the largest average breadth of field for the emmetropic group and the smallest for the presbyopic group. In order from largest to smallest the groups rank as follows: emmetropes, hyperopes, myopes, and presbyopes. The above comparisons are shown in tabular form in table 1.

(2) The range of variation for the color fields is much larger than for the form field. A comparison of the ranges is given in table 2. In this table the range of average breadth of field in the eight principal meridians is given in degrees and per cent for the total number, the middle ninety per cent, the middle eighty per cent, and the middle fifty per cent of cases. In computing the per cent range the average value for the group in question was used as the base.

(3) In general the widest range of variation for field, estimated in terms of per cent, was found for the myopic group and the narrowest for the emmetropic group. The order from greatest to least is myopes, presbyopes, hyperopes, emmetropes. These ranges for the different colors and for the form field are given in table 3. In this table the range of variation of average breadth of field in the eight principal meridians is given in degrees and per cent for the total number, the middle eighty per cent, and the middle fifty per cent of cases for each refraction group. In computing the per cent range the average value for the group in question was used as the base.

(4) The distribution of cases is in general of the same type as was found for the form field; that is, the results when plotted approximate roughly the normal or Gaussian frequency curve. The approximation is

Table 1

SHOWING THE AVERAGE BREADTH OF FIELD FOR THE DIFFERENT REFRACTION GROUPS FOR THE CLINIC CASES.

Stimulus	Average breadth of field					
	Myopes and presbyopes	Emmetropes and hyperopes	Emmetropes	Hyperopes	Myopes	Presbyopes
Blue	39.4	44.1	44.2	44.0	41.2	37.7
Red	34.1	38.5	38.4	38.6	36.6	31.8
Green	20.7	26.5	28.2	25.5	23.3	17.9

Table 2

SHOWING A COMPARISON OF THE RANGE OF SIZE OF FIELD FOR COLOR AND FORM FOR THE CLINIC CASES.

Stimulus	Range of size of field											
	Total number of cases			Middle 90 percent of cases			Middle 80 percent of cases			Middle 50 percent of cases		
	Limiting values	Degrees	Per cent	Limiting values	Degrees	Per cent	Limiting values	Degrees	Per cent	Limiting values	Degrees	Per cent
Blue	60.4–29.1	31.3	74	53.1–32.5	20.6	49	49.3–35.0	14.3	34	46.1–37.6	8.5	20
Red	59.9–20.1	39.8	108	49.5–28.8	20.7	57	45.9–29.3	16.6	46	40.9–32.4	8.5	24
Green	46.9– 9.6	37.3	151	38.0–12.0	26.0	105	34.6–15.6	19.0	77	29.5–19.5	10.0	41
White on black	74.4–59.9	14.5	24	70.8–62.3	8.5	13	70.0–63.0	7.0	11	68.1–64.6	3.5	5

not so close, however, for the color fields as for the form field.

Because of the greater range of variation of fields and the large amount of scatter among the cases with narrow fields, the use of color fields for diagnosis presents greater difficulties than the form field. A difficulty is presented also by the greater overlapping of the scatter for the refraction groups. For all of these reasons a borderline or suspicious group can not be delimited as satisfactorily for color as for form. However, it can probably be safely concluded that the field of an emmetrope or hyperope that has an average breadth of less than 34 to 35 degrees for blue, 30 for red, or 16 for green in eight principal meridians must be classed as suspicious. For a myope or presbyope the borderline probably falls near 32 to 34 degrees for blue, 28 degrees for red and 12 to 14 degrees for green. In case area of field is taken as the index, the borderline for emmetropes and hyperopes may be taken as approximately 50 sq. cm. for blue, 40 sq. cm. for red, and 10 to 12 sq. cm. for green; for myopes and presbyopes 40 sq. cm. for blue, 30 sq. cm. for red, and 5 to 7 sq. cm. for green.

In figures 7 to 9 maps are given showing for each of the colors the largest, average, and smallest fields, and the outer boundaries of the two groups that have been called borderline or suspicious. Of these latter two sets of fields, X represents the widest of the fields whose average breadth in the eight meridians falls below 34 degrees for blue, 28 for red, and 12 for green. Any field smaller than this we have called suspicious for myopes or presbyopes. Y represents the widest of the fields whose average breadth in the eight meridians falls below 36 degrees for blue, 30 for red, and 16 for green. Fields smaller than these for emmetropes or hyperopes may be regarded as suspicious. An exaggerated impression of the variation of size of field is given by the maps because of the

Table 3

SHOWING A COMPARISON OF THE RANGE OF SIZE OF COLOR AND FORM FIELDS FOR THE DIFFERENT REFRACTION GROUPS FOR THE CLINIC CASES

Stimulus				Range of size of field					
	Total number of cases			Middle 80 per cent of cases			Middle 50 per cent of cases		
	Limiting values	Degrees	Per cent	Limiting values	Degrees	Per cent	Limiting values	Degrees	Per cent
A: Emmetropes									
Blue	56.0–34.6	21.4	48	50.5–38.8	11.7	27	47.9–40.8	7.1	16
Red	50.1–29.4	20.7	51	47.4–32.4	15.0	39	40.9–34.3	6.6	18
Green	46.9–16.5	30.4	108	40.4–19.6	20.8	75	32.4–22.4	10.0	37
White on black	73.0–62.9	10.1	15	70.4–64.3	6.1	9	69.8–65.3	4.5	7
B: Hyperopes									
Blue	57.0–35.3	21.7	49	49.5–38.3	11.2	26	46.5–40.8	5.7	13
Red	58.6–30.6	28.0	73	45.9–31.5	14.4	38	41.4–33.6	7.8	21
Green	40.1–14.1	26.0	102	34.3–17.6	16.7	67	29.8–20.6	9.2	37
White on black	74.4–60.6	13.8	20	70.6–64.5	6.1	9	68.3–65.6	2.7	4
C: Myopes									
Blue	60.4–31.0	29.4	71	46.8–32.8	14.0	34	45.5–35.8	9.7	24
Red	59.9–25.8	34.1	96	43.3–29.1	14.2	40	39.4–30.4	9.0	25
Green	36.9–11.8	25.1	108	35.6–15.1	20.5	88	28.1–16.8	11.3	50
White on black	72.0–59.9	12.1	19	69.5–61.5	8.0	12	67.0–62.9	4.1	6
D: Presbyopes									
Blue	48.5–29.1	19.4	51	45.1–31.9	13.2	36	39.9–33.0	6.9	19
Red	46.9–20.1	26.8	84	40.3–26.9	13.4	43	33.3–28.8	4.5	15
Green	33.4– 9.6	23.8	133	31.6– 9.6	18.5	106	22.4–11.9	10.5	64
White on black	69.1–61.0	8.1	13	67.3–62.8	4.5	6	66.1–63.3	2.8	4

exceptionally wide fields of two observers in the group—one for blue and red, the other for green.

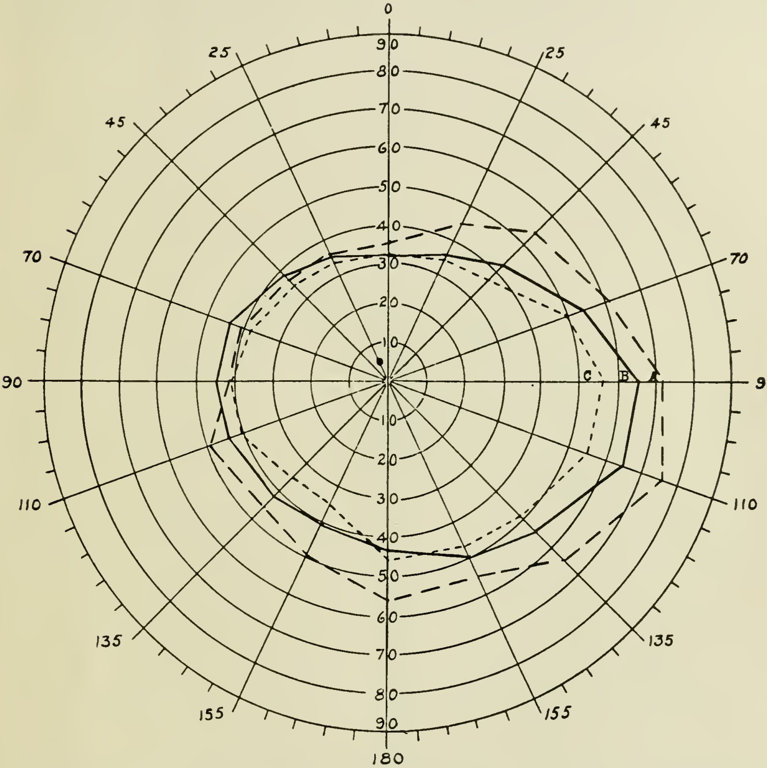

Fig. 10 (Ferree, Rand, and Monroe). Fields for blue; showing the widest field, A, for fifteen nonpathological cases; the average field, B; and the narrowest field, C. The observers used in this and the two following charts showed no errors of refraction when examined without a cycloplegic: they were under twenty-six years of age and were of 6/6 acuity or better. The fields were taken in sixteen meridians and under laboratory conditions.

As in the former paper on the form field, data will be added for fields taken under laboratory conditions (figures 10 to 12)[2]. For these determinations the same observers were used as in the former work. They were all under twenty-six years of age (range twenty to twenty-six), showed no errors of refraction when examined without a cycloplegic, and had an acuity of six-sixths or better under five foot-candles of illumination. Of the cases classed as emmetropic in the clinic group, seven showed no error of refraction without a cycloplegic: these all had an acuity of six-sixths or better and ranged in age from thirteen to thirty-five years. In the laboratory study the fields were determined in sixteen meridians instead of eight, and the observers were given enough practice to secure in each case a close reproducibility of result. The same instrument, stimuli and external controls were used as in the clinic work. The method was in general the same, with the exception that the greater care and precautions possible in laboratory work were used. In general larger fields were obtained than in the clinic studies and a much narrower range of variation. The difference between the laboratory and clinic results in these respects was much greater for the color fields than for the form field.

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[2] These fields were taken by F. Selligman and R. Beardsley.

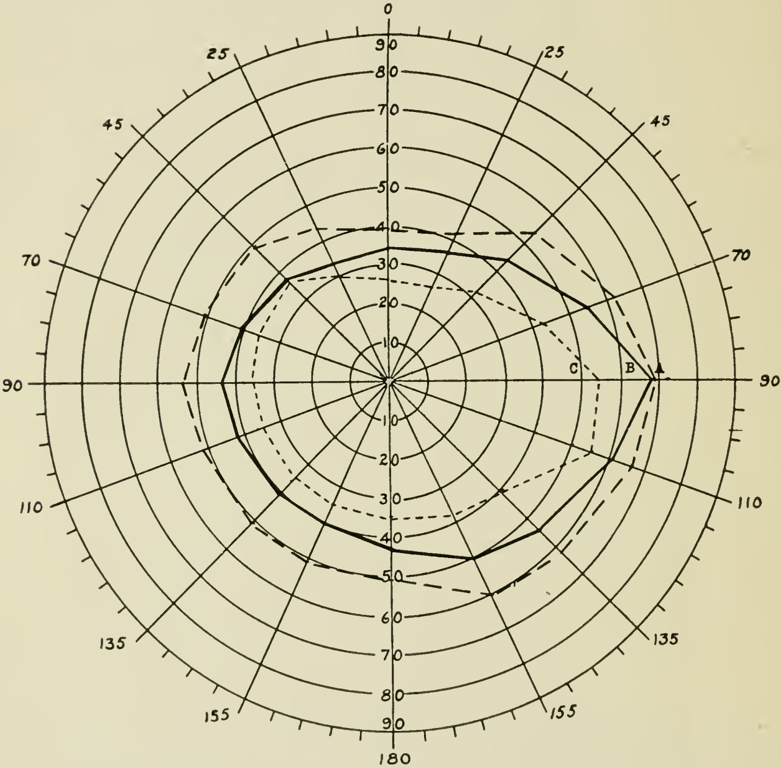

Fig. 11 (Ferree, Rand, and Monroe). Fields for red; showing the widest, average, and narrowest fields for fifteen nonpathological cases.

In the laboratory study the average breadth of form field in the sixteen meridians for the fifteen observers used was 67.5 degrees: the average in the clinic determinations, two hundred observers, was 66.4 degrees. In the laboratory study of the color fields, fifteen observers, the average breadth of field for blue was 46.1 degrees, for red 45.9 degrees, and for green 38.4 degrees. In the clinic study, 126 observers, the average breadth of field for blue was 42.3 degrees, for red 36.8 degrees, and for green 24.7 degrees. In the laboratory study the form fields varied from 62.3 to 72.6 degrees, a range of fifteen per cent; in the clinic study from 59.9 to 74.4 degrees, a range of 24 per cent. In the laboratory study the fields for blue varied from 41.7 to 51.2 degrees, a range of 21 per cent; in the clinic study from 29.1 to 60.4, a range of 74 per cent. In the laboratory study, the fields for red varied from 37.4 to 55 degrees, a range of 38 per cent; in the clinic study from 20.1 to 59.9

degrees, a range of 108 per cent. In the laboratory study the fields for green varied from 24.9 to 50.6 degrees, a range of 67 per cent; in the clinic study from 9.6 to 46.9 degrees, a range of 151 per cent. In computing these percentages the average value for the group of results in question was taken as the base.

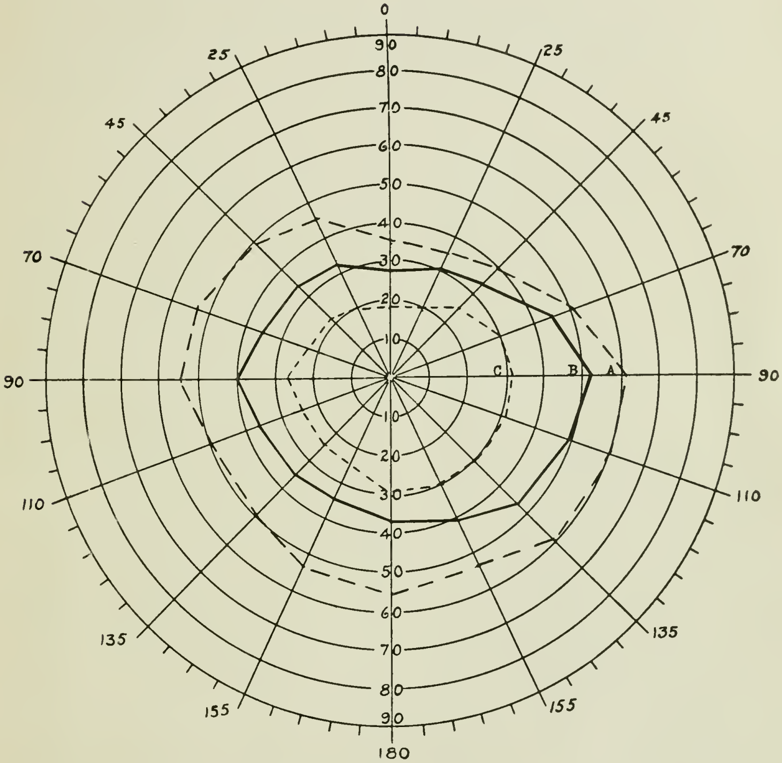

Fig. 12 (Ferree, Rand, and Monroe). Fields for green; showing the widest, average, and narrowest fields for fifteen nonpathological cases.

That the differences recorded above between the laboratory and clinic results for the color fields are not due entirely to the difference in the number of cases examined is rendered probable by the following facts: (a) The differences are much greater than they were for the form field although the same observers were used in the laboratory study as were used for the form field, and a smaller number of the same observers in the clinic study. (b) The average breadth of field for the emmetropic group for the clinic and laboratory studies was about the same for the form field, and the range was even a trifle less for the clinic than for the laboratory study. For the color fields, however, the average breadth of field was considerably less for the clinic than for the laboratory study, and the range was considerably greater, even though a smaller number of cases was used for the color fields in the clinic study than was used for the form field.

Wilmer Ophthalmological Institute.

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STUDIES IN PERIMETRY: 3, ERRORS OF REFRACTION, AGE, AND SEX IN RELATION TO SIZE OF THE FORM FIELD

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Two hundred individuals were studied. Tables show, among other details, the frequency of occurrence of each group of size of field for each age group, the number of cases of each sex tested in the various refraction groups, and the average breadth of field in degrees for each group. It is concluded that errors of refraction are an important factor in variability of size of the form field from individual to individual, that after forty years age is also an important factor, and that sex is apparently not a factor of sufficient importance to take into account in diagnosis.

In former papers results were given to show the influence of variable factors in different types of study of the visual field, and apparatus and methods were described for the standardization and control of all the factors that were amenable to control by experimental methods. In the last two of these papers[1] a method of treatment of the remainder of the factors was outlined, namely those which vary from individual to individual; and preliminary data were presented for the formation of diagnostic scales for the form and color fields. It was also indicated in these papers that as fast as possible data would be given showing the influence of these factors on the size of the form and color fields. It is the purpose of the present paper to show the relation of three of them, errors of refraction, age, and sex, to the size of the form field for a stimulus subtending a visual angle of one degree. The influence of these factors can not be shown directly by experimental variation as was the case with the factors which vary for a given individual. The procedure used has been to collect the data under standard conditions of control for a group of nonpathological individuals, sampled to include the factors under investigation, and to determine the influence of these factors by statistical study so far as was possible in the situation presented. The results derived from such a procedure are not so clear-cut and incisive as are those obtained by the experimental method, but the procedure used is the only one available in cases in which experimental analysis is not possible.

The fields were taken on the Ferree-Rand perimeter, with strict observance of all the precautions prescribed for the use of this perimeter. With this instrument all of the external conditions of the test can be held constant and can be reproduced at will. The fields were determined with a white stimulus on a black background. The coefficients of reflection of stimulus and background were respectively seventy-eight and four per cent. The illumination at every point in the field was kept constant at seven foot-candles. The cases examined included private patients, doctors, nurses, assistants on the hospital staff, and a large number of clinic patients. In every instance the refractive condition of the eye was carefully determined and an ophthalmoscopic examination made. No cases showing a pathological condition, however slight, were included in the series. Ample rest periods were allowed between observations, and care was exercised that no field should be taken when the observer was suffering from general fatigue or was otherwise unfit for accurate work. All determinations were carefully checked, but the observer was not given extensive preliminary training. It was not the purpose of the writers to make examinations for determining the influence of the factors in question under conditions differing in this respect from those which obtain in the ordinary practice of perimetry. The results obtained may, therefore, be considered a fair sample of the effects that may be expected in an average group of untrained observers who show no pathology.

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[1] Studies in perimetry. 1, preliminary work on a diagnostic scale for the form field. Amer. Jour. Ophth., 1926, v. 9, pp. 95-104.

Studies in Perimetry. 2, preliminary work on a diagnostic scale for the color fields. Amer. Jour. Ophth., 1929, v. 12, pp. 269-285.

Fields were determined in eight meridional quadrants (0, 45, 90, 135, 180, 225, 270, and 315 degrees). The eyes examined included seventy-five cases of hyperopia and hyperopic astigmatism, thirty cases of myopia and myopic astigmatism, forty cases of presbyopia, five cases of mixed astigmatism, and fifty cases showing no error of refraction or an error no greater than one diopter of hyperopia or a quarter diopter of hyperopic astigmatism. This latter group contained no cases of myopia or myopic astigmatism of a detectable amount. For convenience of treatment it will be referred to as emmetropic. The observers ranged in age from eight to fifty-six years. There were eighty-four males and 116 females.

In making comparisons of the kind considered in this paper a single value or index is needed to represent size of field. Two types of index have been discussed and used in our former papers; the average extent or breadth of field in the eight meridional quadrants, and the area of field as measured with a planimeter on a map drawn to a predetermined scale. The former of these has been selected for use in the present paper.

The relation of errors of refraction to size of field has already been shown and discussed at some length in a previous paper. In the present paper the relation is shown in the form of frequency curves for each type of error of refraction, similar in principle to the distribution curve. These curves are given in figure 1.

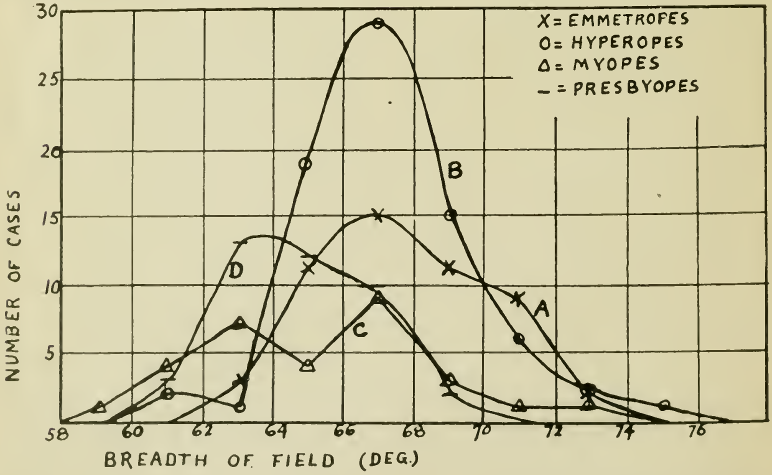

Fig. 1. (Ferree, Rand, and Monroe). Showing the distribution of the 200 nonpathological cases for each refraction group: A, emmetropes; B, hyperopes; C, myopes; D, presbyopes. The distributions are based on average breadth of field in the eight principal meridional quadrants.

In these curves average breadth of field in the eight meridional quadrants, expressed in degrees, is plotted on the horizontal coordinate, and number of cases on the vertical coordinate. The type of error of refraction is designated by a key shown in the plot.

In the consideration of these graphs the question of causes of relation between error of refraction and size of field naturally arises. The following possibilities are suggested:

(a) Indistinctness of the image in the more extreme cases of refraction defect. The consideration of this possibility for the cases in question is complicated, however, by lack of knowledge of the refraction situation for the peripheral hyperopia due to deficient curvature of the cornea one might expect as a phenomenon of refraction that the image for a given excentricity of stimulus in the field would be formed nearer to the center of the retina than for the same position of the stimulus in cases of emmetropia and myopia. The tendency of this factor would be to widen the field for hyperopia. Conversely, in cases of myopia due to excessive curvature of the cornea one might expect for portions of the field. In our more detailed and scientific work in the study of the peripheral field we have been accustomed to determine its refraction. In a study of the kind made here such a detailed specification of condition of refraction was quite impossible.

(b) The placement of the image on the retina. For example, in cases of a given excentricity of the stimulus in the field that the image would be formed relatively farther from the center of the retina. The influence of this factor would tend to narrow the field in myopia.

(c) Characteristic differences in shape of eyeball, in the degree of development and sensitivity of the nervous structure and in the health of the eye.

(d) Age as a dominant factor in presbyopia.

With the exception of (d) the data presented in the paper do not justify any serious attempt at a differential evaluation of the possibilities suggested. It may be noted, however, that the sizes of field obtained in the greater number of cases of hyperopia and myopia are in the direction that might

Table 1

SHOWING, FOR EACH AGE GROUP, THE NUMBER OF CASES IN EACH RANGE OF SIZE OF FORM FIELD

	Range of breadth of form field					
Age	58-61.9	62-65.9	66-69.9	70-73.9	74-77.9	Total
0- 9			1			1
10-19		14	28	5		47
20-29	4	19	36	12	1	72
30-39	2	10	17	4		33
40-49	4	16	10			30
50-59		14	3			17
Total	10	73	95	21	1	200

Table 2

SHOWING, FOR EACH AGE GROUP, THE PERCENTAGE OF CASES IN EACH RANGE OF SIZE OF FORM FIELD

	Range of breadth of form field					
Age	58-61.9	62-65.9	66-69.9	70-73.9	74-77.9	Total
0- 9			0.5			0.5
10-19		7.0	14.0	2.5		23.5
20-29	2.0	9.5	18.0	6.0	0.5	36.0
30-39	1.0	5.0	8.5	2.0		16.5
40-49	2.0	8.0	5.0			15.0
50-59		7.0	1.5			8.5
Total	5.0	36.5	47.5	10.5	0.5	100

be expected from the factor of curvature of cornea.

Tables 1 and 2 have been compiled to show the relation between age and average breadth of form field in the eight principal quadrants. The range of size of field is treated in five groups of four degrees each, the range of age in years in six groups of ten years each. The rows of table 1 show the frequency of occurrence of each group of size of field for each age group; while the columns show the frequency of occurrence of each age group for each size of field. In table 2 is shown the percentage of occurrence of each group of size of field for each age group.

Inspection of these tables indicates that there is some tendency for size of field and age to vary concomitantly, the larger fields occurring at the younger ages. The coefficient of correlation between age and size of field computed by the product-moment formula of Pearson for linear relationship is —0.31 ±0.04.[2] The table shows, however, a slight nonlinearity of relationship due to a pronounced shift towards smaller fields near forty years of age. That is, above forty years the mode (the value on the scale that occurs most frequently) falls in the group 66 to 69.9 degrees (average 68), while below forty years the mode falls in the group 62 to 65.9 degrees (average 64). Between thirty and forty years a transitional stage is seen where there is more nearly an equal number of cases in the groups whose averages are respectively 68 and 64.

This shift of the mode downward at forty years of age and the transitional stage between thirty and forty years will be shown in a later paper to occur also for the color fields. The average size of field for the age group ten to nineteen is 67.0 degrees; for the age group twenty to twenty-nine is 67.5 degrees; for the age group thirty to thirty-nine is 66.8 degrees; for the age group forty to forty-nine is 64.8 degrees; and for the age group fifty to fifty-nine is 64.7 degrees.

In figure 2 the data have been plotted to show separately the distribution of cases below and above forty years of age. Curve A gives the distribution of the 153 cases below forty years of age; curve B the distribution of the forty-seven cases above forty years of age. For ease of comparison the data for curve B have been replotted in curve C on a magnified scale. The factor of magnification used was 3.25, the ratio of the number of cases in the two groups.

It may further be noted that no very large fields (more than seventy degrees) occur above the age of forty and no very small fields (less than sixty-two degrees) below the age of twenty years. These characteristics are also in general found for the color as well as for the form fields.

The narrower fields of the presbyopic group are probably largely a phenomenon of age rather than an effect of presbyopia. That is, presbyopia, the loss of sensitivity, and the general failure of all the powers of the eye are in the main coordinate rather than interdependent phenomena of age. However, in the more advanced cases of presbyopia the defective focusing for close vision, due to loss of accommodation, doubtless exerts a direct influence on the results of perimetry when the stimulus is viewed at a distance of 33 cm. Other age phenomena, extraneous to the functional changes in the sensory mechanism, which may exert an influence on the perimetric results are opacities of the cornea, lens, and vitreous; changes in size of pupil; and so on.

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[2] For the benefit of nonstatistical readers, the following brief note of explanation is appended: The Pearson product-moment formula is the accepted statistical procedure for computing an index which represents the degree of correspondence existing between two variables. Perfect positive correlation is indicated by +1, that is, large values of the one variable correspond to large values of the other; perfect negative correlation is indicated by —1, that is, small values of the one variable correspond to large values of the other; lack of correlation is indicated by 0. The coefficient of correlation of —0.31 found above shows that there is a tendency for large values of size of field to occur with small values of age, and conversely. The probable error ±0.04 indicates that the chances are even that the true value of the coefficient of correlation lies within the limits —0.31 ± 0.04. That is, with other samples of unselected nonpathological subjects, the chances are that the coefficient of correlation between age and size of form field would fall between —0.27 and —0.35.

The results have further been studied to show what relation, if any, exists between sex and the size of the form field. The 200 cases studied included 84 males and 116 females. The median value of size of field rated in terms of average breadth is 66.4 degrees. For the males the average breadth of field for thirty-six cases, or forty-three per cent of the number tested, falls above and for forty-eight cases, or fifty-seven per cent of the number tested, below this value. For the females, the average breadth of field for sixty-four cases, or 55 per cent of the number tested, falls above and for fifty-two cases, or forty-five per cent of the number tested, below this value. The average breadth of field for the males is 66.04 degrees; for the females 66.75 degrees.

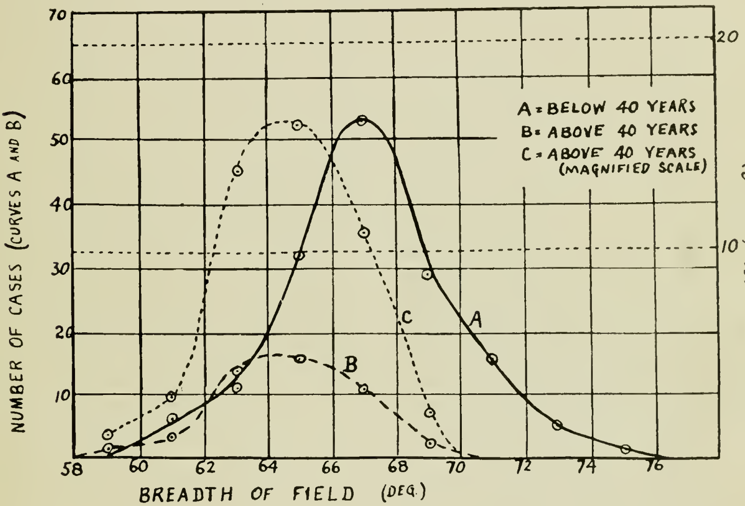

Fig. 2. (Ferree, Rand, and Monroe). Showing for comparison the distribution of the nonpathological cases below and above forty years of age. In curve A are represented the 153 cases below forty years of age; in curve B the 47 cases above forty years of age; and in curve C the cases above forty years plotted on a magnified scale, the factor of magnification being 3.25, the ratio of the number of cases in the two age groups. The distributions are based on the average breadth of field in the eight principal meridional quadrants.

Table 3 gives the number of cases of each sex tested in the various refraction groups and the average breadth of field in degrees for each group. It is seen that the averages for the females are slightly but consistently larger than for the males in each group. The difference is too small to be significant in diagnosis, but it presents a possible point for further study. Whether it represents an actual difference in spread of sensitivity is problematic. The result may be due to other causes. Among these may be mentioned differences in facial conformation: the deeper set eyes, the more prominent nose, the overhanging brows, and so on of the males. Some information as to the importance of the factor could be obtained perhaps from a study of the fields for the two sexes meridian by meridian. Sex differences and their analyses will be made the subject of more extensive study should the data

Table 3

Showing the number of cases of each sex studied in each refraction group and the average breadth of field

Refraction group	Sex	Number of cases	Average breadth of field (degrees)
Emmetropia	M	22	67.42
	F	28	67.73
Hyperopia	M	28	66.42
	F	47	67.54
Myopia	M	12	64.98
	F	18	65.25
Presbyopia	M	17	64.54
	F	23	65.09
Mixed astigmatism	M	5	65.50
	F	0	
Entire Group	M	84	66.04
	F	116	66.75

obtained in later work show that the point is of sufficient importance.[3]

Conclusions may be stated as follows: (1) Errors of refraction are an important factor influencing variability of size of the form field from individual to individual. (2) After forty years age is also an important factor; while earlier than this the effect of age is negligible. (3) Sex is apparently not a factor of sufficient importance to be taken into account in diagnosis.

Wilmer Ophthalmological Institute

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[3] In this connection the following quotation taken from a letter written to one of the writers by Dr. Henry H. Donaldson of the Wistar Institute of Anatomy and Biology under date of March 26, 1926, is suggestive: "In studying the albino rat we have found the eye bulbs of the female to be heavier than those of the male of like body weight, and the area of the cross section of the optic nerve to be also greater in the female. This last would possibly suggest a slightly greater extension of the retina in the female."

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